THE CONTROL OF TICKS ON LIVESTOCK

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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PREFACE

In many parts of the world national and regional economics are related in no small measure to the incidence of tick-borne diseases in livestock. This has been appreciated for some years and much study has been made of these afflictions and their transmission by ticks. Much information on the part played by ticks has become available and steadily, year by year, increasing knowledge is forthcoming from research work carried out in different countries and from the observations of individuals and teams of workers. There is still much to be done but as this publication shows, the results have led to the adoption of methods and measures for the control of the tick vectors, measures which have been in operation for many years in some areas and which, following new discoveries and experiences, are improved upon from time to time.

Among the activities of international organizations interested in animal health problems, tick-borne diseases have received their share of consideration. In 1956, a meeting on the control of tick-borne diseases of livestock was convened in Rome, jointly by the Food and Agriculture Organization of the United Nations (FAO) and the Office international des épizooties (OIE). Full discussion took place and recommendations were made; and the proceedings were recorded in FAO Meeting Report No. 1956/18. One of the recommendations was that governments should be contacted "with a view to the setting up of a small group of workers on tick-borne diseases which would meet as required to discuss current progress and make recommendations." This was acted upon, with the result that an expert panel on tick-borne diseases of livestock was established in 1958, the membership of which consists of persons in Australia, Europe, Asia, Africa, United Kingdom and the United States of America. A first meeting of the panel, at which the control of tick vectors was the main subject for consideration, was held in London in November 1958, and FAO Meeting Report 1958/24 was

prepared. A recommendation of the panel meeting was that further consideration be given by the sponsoring organizations to the publication from time to time of information on ticks and tick-borne diseases and that a short publication be issued at an early date for the guidance of those countries starting on control measures.

It was felt that the first publication to be issued should be on the control of ticks in livestock, and Dr. S. F. Barnett was requested to prepare the material.

It will be seen that many aspects of tick control are dealt with and many references are given to articles describing work and observations in different regions; much useful material is included. While some or a considerable amount of the information may be already known or available to those actually working on or intimately interested in ticks and tick-borne diseases, the material is presented in such a way that valuable information is made available to all concerned with tick control. It describes the various methods whereby control measures may be adopted and, it is felt, should meet the requirements of those now undertaking or strengthening the measures considered most suitable in any special area.

It can, it is believed, be accepted that the information contained in this publication is as up to date as possible. Doubtless, as research work progresses, new information of importance will be forthcoming from time to time. This will have to be disseminated and will eventually entail a revision of the present publication.

The Organization expresses its gratitude to Dr. Barnett and appreciation of the assistance given by the Cooper Technical Bureau, Berkhamstead, England, for permission to reproduce the illustrations in the publication, which add so considerably to the information contained in this volume.

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INTRODUCTION

The purpose of this publication is to provide a broad survey of the methods which are available for controlling ticks and to give practical details of the methods of proven efficacy.

Effective control necessitates a thorough knowledge of the tick species involved, especially its biology and behavior, but in this publication only some more general reference to this intricate subject can be made. The methods of control employed are largely determined by the economics of the situation and vary from sporadic control by individual owners of a few head of stock to intensive control on a national scale. Where a tick species acts as a vector of disease, eradication of the disease may be attempted by reducing or eliminating the tick vector. In such cases, the cost of eradication could be very high and take many years, but if successful, it would result in freedom from the continuous drain of disease and the cost of consistent attempts at control by individual owners. Eradication schemes use well-established methods but in an intensified form and involve the enforcement of rigid regulatory systems to ensure their effectiveness and permanency. Details of the regulatory systems are not dealt with here.

In most cases ixodicides and the methods of their external application, which effectively control ticks, will also kill other ectoparasites such as lice, mites, keds, fleas, etc., but not of necessity control them.

It is hoped that the present publication will stimulate scientists to communicate their knowledge, so that a revised edition may be issued, for it is fairly certain that with the rapid advances in the development of ixodicides, this will be necessary before very long. It is likely that a second edition will include detailed information on the life cycle and

behavior of the different species of ticks in various parts of the world, since future control measures will make use of the biological weaknesses of the species to a much greater extent than at present.

The line drawings which illustrate this article were drawn by Mr. A. G. Rayner, and the author is grateful to him and to the Cooper Technical Bureau, which permitted their reproduction and whose assistance and library facilities enabled the author to prepare this publication.

I. REASONS FOR CONTROLLING TICKS

Parasitization of stock with ticks produces injury in three respects: (*a*) direct damage caused by parasitism such as local injury and blood loss; (*b*) by toxins injected by the parasites; and (*c*) by the transmission of disease.

Direct injury

It is difficult to produce factual evidence in terms of monetary loss from the results of mechanical damage caused by tick infestation but it is rightly accepted that losses to the livestock industry from this cause are very considerable. The annual loss caused by cattle ticks in Queensland, Australia, is given as £ 9,579,000 (Bureau of Agricultural Economy, Canberra, 1959). About half of this amount is due to loss of production and deaths in which tick-borne diseases as well as mechanical damage play a part. The remainder is accounted for by damage to hides, cost of ixodicides and labor costs. This loss must be incurred to control ticks even in the absence of tick-borne disease, and it takes no account of capital depreciation on plants, such as dips and sprays, nor of state and federal expenditure on regulatory control and research. Detectable injury due to blood loss may be marked when large numbers of ticks are feeding; this occurs particularly with the various species of *Boophilus*. A single adult female will remove from 0.5 to 2.0 milliliters of blood, and as animals can each carry several thousand ticks, they can suffer a daily blood loss of several hundred milliliters. The degree of blood loss is obviously harmful and sometimes fatal. It is difficult to give precise figures for the number of ticks which could kill domestic stock from the effects of exsanguination, but theoretically, the simultaneous feeding of 6,000 to 10,000 female ticks could kill an adult bovine. In practice, cattle can withstand the feeding of much larger numbers of ticks, as has been

shown experimentally in Australia, where 20,000 adult *Boophilus* failed to kill a steer but 500 were capable of killing a calf. It was also shown that cattle in good bodily condition withstood the infestation of large numbers of ticks better than did animals in poor condition, and that the blood constituents of the former were restored to normal more rapidly after removal of the ticks (Riek, 1957). Riek thought that toxic secretions from the ticks might help to account for the slow recovery of the heavily infested animals in poor condition, even after the ticks had been removed and adequate food provided. Fatalities from exsanguination are recorded in the moose from infestation with *Dermacentor albipictus* (Fenstermacher and Jellison, 1933) and in the horse from infestation with *Boophilus decoloratus* (Theiler, 1911). As few as 80 *Dermacentor andersoni* killed a rabbit of 2 to 3 kilograms body weight (Jellison and Kohls, 1938). Chickens can also die from exsanguination from the feeding of *Argas persicus*, and Lucas (1954) records deaths and injury in fowls infested with *Haemaphysalis hoodi*. Fatal anemia in sheep ascribed to heavy infestation with *D. andersoni* has been recorded in Montana (Philips, Jellison and Wilkins, 1935).

It is less easy to measure the effect of the continuous feeding of a few hundred ticks, which is the common degree of infestation of cattle in many parts of the world. Under conditions of good food supply, compensatory production for the loss of blood would take place, but at the expense of the animal's productive resources. Under the poor feeding conditions which are commonly associated with such tick infestations, adequate compensation is not possible, resulting in debility and loss of condition.

A less tangible form of injury is recognized by stockowners under the name of "tick worry." It is concerned partly with the local irritation at the site of feeding, partly with blood loss, and partly with the secondary infections with bacteria or dipterous larvae following tick bites. The importance of this complex of conditions is difficult to evaluate. One is impressed by the sleekness and better condition of dipped cattle compared with undipped animals on the same type of tick-infested grazing, but elimination or reduction of ticks by dipping also reduces the numbers of other ectoparasites and biting flies, and data showing improved weight gains or milk yields (Basu *et al.*, 1952) following dipping may lead to an overestimate of the harm done by tick worry. Nevertheless, it is certain that tick worry is an important source of loss to the livestock industry, as illustrated by the figure quoted by Norman (1957), who records an

increase of liveweight gained of over 200 percent in the Northern Territory of Australia following the control of ticks. In South Africa, Thomas and Neitz (1958) believe that this type of condition is aided by toxins produced by *Rhipicephalus appendiculatus*, and the name "tick toxicosis" is used to describe it.

Secondary infection of lesions produced by tick bites is a common cause of loss and injury. It may cause death in young lambs, lameness in all infested stock, suppuration of the internal and external ear, purulent wounds of the udder (Orlov *et al.*, 1954), mastitis and possibly orchitis. It is believed that the spread of *Cryptococcus farciminosus* and *Corynebacterium ovis*, causing lymphangitis in the equidae, is facilitated by the sores resulting from tick bites. The specific disease "tick pyaemia" of lambs was thought to be transmitted by the tick, but Foggie (1947) showed that the *staphylococci* causing the condition were derived from the skin and entered the body through the lesion produced by ticks, so that this fatal and debilitating condition of lambs must be classed among the other causes of mechanical injury. Sores from tick bites often become infested with "screw worm." Screw worm "strike" of cattle in the Southern States of the United States caused enormous losses before sterilized male control was instigated (U.S.D.A. Yearbook, 1956).

Apart from the mechanical effect of ticks on the health of livestock, great importance is attached to the damage caused to hides by tick bites. The extent of this damage has been stressed in various parts of the world and is estimated to amount to millions of dollars a year.

Transmission of toxins

The existence of a specific intoxication induced by tick bites is recognized all over the world in practically all species of animals and in man. Mention has been made earlier of a tick toxicosis of cattle in South Africa, which is a compounded effect of tick-borne disease, exsanguination, and some toxic effect of the ticks themselves. The specific condition of "tick paralysis" is caused by the injection of a toxin by certain instars of ticks, usually the adult female but sometimes by nymphae. The genus *Ixodes* is particularly associated with this condition but ticks of other genera can cause it, such as *Ornithodoros lahorensis* (Kusov, 1955; Mihailov, 1957) and *Dermacentor andersoni* (O'Rourke and Murnaghan, 1954; Gregson, 1957). The paralysis is associated with the later stages of the feeding of the tick, especially those which attach to the head and neck

of the host. The degree of paralysis is proportional to the length of time the tick has been feeding and, frequently, on the number of ticks attached (e.g., *I. holocyclus*), and recovery of the infested animal is the rule if the tick is promptly removed. Tick paralysis is generally observed in isolated cases of individual animals, but it can affect herds of animals and cause severe losses if untreated (Jellison *et al.*, 1951).

Sweating sickness is a disease of South, Central and East Africa affecting cattle, sheep, goats and pigs. Like tick paralysis, it usually occurs sporadically. It is caused by *Hyalomma truncatum* and has all the characteristics of a toxicosis. The adult stage of the tick conveys the toxin to domestic stock, and although the immature stages normally feed on small mammals, the adults still transmit the infection. Even ticks which have been reared for many generations on unsusceptible animals still retain the power to transmit the toxin (Neitz, 1956 and 1959).

Transmission of disease agents

There is a wide range of bacterial, viral, rickettsial and protozoal diseases transmitted by ticks in all parts of the world. Some diseases, such as those due to *Babesia* and *Anaplasma* infections are widely distributed; others, such as those caused by *Rickettsia ruminantium* are more restricted. This is, in part, due to the distribution of the tick vector, but it is beyond the scope of this publication to discuss the distribution of all the vectors. A list of the important diseases known to be transmitted by ticks is given in Table 1. The details of the tick vectors of these diseases have been summarized in FAO Meeting Report No. 1956/18.

TABLE 1. — Disease agents of domestic stock transmitted by ticks

A. VIRUSES	
Louping-ill	Sheep, cattle, horses
Russian spring-summer encephalitis	Sheep, goats (carriers but not clinically affected)
Nairobi sheep disease	Sheep and goats
Kisenyi sheep disease	Sheep

Equine encephalitis (western type)	Horses (experimental)
Encephalitis	Camels
B. RICKETTSIAE	
Rickettsia (Cowdria) *ruminantium*	Cattle, sheep, goats
Rickettsia bovis	Cattle
Rickettsia (Cowdria) *ovina*	Sheep
Rickettsia (Erlichia) *canis*	Dogs
Rickettsia phagocytophilia	Cattle, sheep, goats
Coxiella burneti	Most domestic animals
C. BACTERIA	
Pasteurella tularensis	Domestic and wild animals
Brucella melitensis	Domestic and wild animals
Brucella abortus	Domestic and wild animals
Listerella monocytogenes	Domestic and wild animals
Staphylococcus aureus	Sheep
D. SPIROCHAETES	
Borrelia anserina	Poultry
Borrelia theileri	Cattle, horses, sheep, goats
E. PROTOZOA	
Babesia bigemina	Cattle
Babesia bovis	Cattle
Babesia argentina	Cattle

Babesia berbera	Cattle
Babesia motasi	Sheep, goats
Babesia ovis	Sheep, goats
Babesia caballi	Horses, donkeys, mules
Babesia equi	Horses, donkeys, mules
Babesia trautmanni	Pigs
Babesia peroncittoi	Pigs
Babesia canis	Dogs
Babesia gibsoni	Dogs
Babesia felis	Felines
Theileria parva	Cattle, buffalo
Theileria annulata	Cattle, buffalo
Theileria sergenti	Cattle
Theileria lawrenci	Cattle, buffalo
Theileria orientalis	Cattle
Theileria mutans	Cattle
Theileria ovis	Sheep, goats
Theileria hirci	Sheep, goats
Anaplasma marginale	Cattle, wild ruminants
Anaplasma centrale	Cattle
Anaplasma ovis	Sheep, goats, wild ruminants

The mere list of diseases is formidable and the effect of the diseases on the livestock industry is equally great. Some disease agents are important because of their lethal or debilitating effect on the host; others, such as *Coxiella* and the encephalitides, because livestock may act as reservoirs of infection to human beings. Some of the disease agents may also be transmitted by vectors other than ticks or by mechanical means from one

host to another; nevertheless, the tick vector must usually be controlled or eliminated in order to control the disease.

There are comparatively few assessments of the economic loss resulting from infection with tick-borne diseases, but it is accepted that this group of disease agents causes enormous loss of animal life and productivity throughout the world.

The total effect of ticks on the livestock industry of the world, whether by damage as parasites, transmitters of toxins, or vectors of disease, is incalculable. The cost to individuals and to governments of preventing tick damage and tick-borne disease is very great. For this reason, many countries have carried out or are attempting the long-term project of total eradication of the more important diseases and the ticks which transmit them. South Africa has been fighting East Coast Fever for over 40 years, and the disease is now within sight of eradication. In the United States of America, where the estimated annual loss was over 40 million dollars, the eradication of *Boophilus annulatus* and *Babesia bigemina* was affected after nearly as long a struggle, but *Boophilus* was eradicated from the Virgin Islands in a comparatively short time by 14-day dipping in 0.18 percent arsenic solution (Hall, 1951).

The reduction or eradication of ticks and tick-borne disease demands as much knowledge as possible of the biology and behavior of the ticks, the parasite and the host, and some indication of the application of this knowledge is given in Chapter III of this publication. The struggle against ticks and disease is made easier by an informed and co-operative stockowner. It requires the patient and unremitting hard work of technical staff, the unwavering support of the administration, and often the active co-operation of neighboring states.

It is hoped that the technical information given in this publication will contribute in some way to the objective of minimizing and ultimately eliminating the toll which is, at present, being exacted from our animal population.

II. CONTROL OF PARASITES OFF THE HOST

Parasites and predators

Natural parasites of ticks have been recorded from many parts of the world; they are hymenoptera of the Encyrtid or the Chalcid groups. The recorded incidence of parasitism and the species involved have been listed by Gertrud Theiler (FAO Meeting Report No. 1958/24); the list is not repeated here.

Attempts have been made to utilize parasitism as a means of controlling tick numbers. A large-scale release of *Hunterellus hookeri* was made by Cooley from 1928 to 1933 in western Montana, which was heavily infested with *Dermacentor andersoni*, without any effect on the population of ticks. Smith and Cole (1943) liberated *H. hookeri* on an island in Massachusetts but the parasite did not appear to survive and no reduction of ticks occurred. In a previous release of parasites on an island in the Cape Cod area by Larrouse *et al.* (1928), the parasite survived but the ticks, *D. variabilis* and *I. scapularis*, remained abundant. Alfeev (1941) reported that *H. hookeri*, liberated in the district of Leningrad, was not recovered later from ticks in the area but suggested that the parasite might have survived further south in a warmer climate.

In nature, the parasites are not plentiful and do not appear to be an important factor in the natural limitation of tick numbers. In cooler climates, inadequate co-ordination of tick and parasite generations is a limiting factor (Cooley and Kohls, 1934). The general concensus of opinion regarding the deliberate spread of tick parasites is that it is not a means which will exert any effective control over tick numbers in the field.

Predators undoubtedly exert some limiting effect on tick numbers in many parts of the world and, in this respect, the host itself must be included, since it has been shown in Australia that very large numbers of larvae are ingested or killed by cattle by self-licking (Riek, 1956).

Snowball (1956) gives figures of 33 percent survival of ticks on animals prevented from licking and only 9 percent survival on animals which were able to lick themselves. Small mammals which are assiduous in cleaning themselves, such as cats and rodents, remove many ticks from their body and only on the inaccessible parts do ticks survive in any considerable numbers. The head and ears of cats escape attention, and in a study of tick infestations on wild mice by the author, the ticks, in a small cluster, were found only on the anterior of the sternum, which was apparently inaccessible to the animal's mouth.

In Africa the tick bird or oxpecker actively removes ticks from domestic and wild mammals. The number of birds is never very great but quite large numbers of ticks must be removed by them (Van Someren, 1951). The value of these birds in tick reduction is counterbalanced by the damage they do to the animal, since they also feed actively on the blood and tissues of the host and will enlarge small wounds and prevent their healing. Another bird species, the white egret, is commonly termed the "tick bird." It feeds in the grass around the feet of grazing cattle, and will occasionally flutter in the air after insects disturbed by the cattle. It is possible, although not proven, that some resting stages of the ticks on the grass are consumed by the birds. Two species of birds have been observed taking ticks from cattle in Australia (CSIRO, 1952) but no comment is made in the report on the extent of their activities. Rats and mice are known to consume ticks, especially the recently engorged stages which are seeking moulting or egg-laying sites on the ground. Their importance in reducing tick numbers in the field is not known.

The most important predators appear to be the predatory ants. In Australia ants of the genera *Iridomyrmex*, *Asphaenogaster* and *Pheidole* have been observed to remove engorged adults on the ground (CSIRO, 1951, 1952, 1955). When engorged adults were placed in an area near Duaringa, which has few ticks, although it is within the tick belt, funnel ants (*Asphaenogaster*) and other ants were observed to take most of the ticks (CSIRO, 1953 b). In an earlier record (CSIRO, 1951), it is stated that meat ants (*Iridomyrmex*) were responsible for the destruction of a high proportion of engorged ticks after dropping from the host but they did not consume larvae or eggs.

In East Africa the comparatively small number of ticks has been noted by the author on cattle in areas which appear climatically suited to unlimited multiplication of the parasites. Experimental observation

of engorged females placed on the ground showed that many were taken by predatory ants, and it was concluded that these predators played an important part in the limitation of tick numbers.

It is unlikely that the incidence of predators can be deliberately or actively influenced as a means of tick control, but their presence or absence is evidently of some importance in the limitation of tick populations.

Alteration of the environment

Climatic conditions largely determine the distribution of tick species throughout the world, but within these broad ecological zones there are more precise conditions of local environment which influence the reproduction and survival of different species. By adopting certain systems of pasture management, cultivation and land usage, which includes the temporary removal of the host, it is possible to alter the local habitat sufficiently to reduce and perhaps even eliminate the tick population in local areas. Considerable knowledge of the ecology and behavior of a tick species is needed for the practical adoption of this method of control, but it has already been used with some success against *Boophilus microplus* and *Ixodes ricinus*. The subject will be discussed under two headings, although there is sometimes a degree of dependence and interrelationship between them: (*a*) alteration of the micro-habitat; and (*b*) removal of the host.

Alteration of the micro-habitat

The occurrence of *I. ricinus* in the United Kingdom is largely restricted to rough grazing and it has been shown by Milne (1944) that the chief factor in the distribution of the tick is the physical character of the vegetation layer and that the basal mat of the vegetation is the essential element of this physical character. The nature of the vegetation can be changed by drainage, harrowing, application of lime, and other methods directed toward the improvement of the pasture for stock. This improvement reduces the damp basal mat and changes the grass and plant population, rendering it difficult for the tick to survive; it also enables the land to be more heavily stocked and grazed, which further changes the micro-habitat, and so the land becomes even more unsuited to the requirements of the tick. A more rapid and radical change of habitat results from plowing and cultivation of the land and planting crops or grass leys. Much of the

land in the United Kingdom which is infested with *Ixodes* is not suited to such cultivation but this method can be applied to more fertile areas.

In Kazakhstan a system of husbandry has been proposed by Galuzo (1944 a), which exposes ticks to unfavorable conditions at many stages of their life cycle. *Hyalomma detritum*, a vector of *Theileria annulata*, is a one- or two-host tick: the adults feed mainly in summer and oviposit in the ground. The larvae shelter in cracks in the ground until October or November, when they ascend the grass and overwinter on cattle in the larval-nymphal stages, and the engorged nymphae drop from February to March. Plowing or disking the pastures in September or October helps to kill the larvae sheltering in the soil cracks; or the larvae can be destroyed by grass burning when they ascend the grass at the end of October or November. In addition, the larvae can be deprived of hosts by housing the stock between October and January. If housing is not possible, the animals are grazed on sparse vegetation, and in both cases treatment of the hosts with ixodicides during the period of October-January is carried out in order to kill the overwintering larval-nymphal stages. Engorged nymphae drop from February to March, and pastures which have been used during this period should be kept free of stock during June, July and August, in order to starve the adult ticks which seek to feed then.

The application of similar but rather complex biological methods to aid the control of *Dermacentor marginatus* which transmits *Babesia* infections of horses has also been proposed by Galuzo (1944 b).

The methods proposed by Galuzo are comprehensive and, providing the resting or cultivation of pastures can be fitted into normal agricultural practice, the tick can be attacked at all stages of its development and, according to Markov (1958), this principle appears to be an adopted policy in the U.S.S.R. Markov states that "control measures are based on attacking the disease agent and the transmitter, and at the same time changing the living conditions of the transmitters unfavorably for them." These measures have been included in veterinary legislation of the Ministry of Agriculture of the U. S. S. R.

In South Africa work carried out by Stampa and du Toit (1948) and later observations of Stampa (1959) on *Ixodes rubicundus*, the Karoo paralysis tick, show how closely this species of tick is dependent on certain vegetational requirements. When all palatable plants are grazed down at least once a year, they are unable to protect the tick. When the plants are left undisturbed for several years, a mass of debris develops beneath them but the shelter so provided is never very efficient. Unpalatable plants,

on the other hand, readily provide efficient shelter, due to the mat of debris formed by the leaf drop. A suitable density of such plants is necessary to provide adequate protection for the maintenance of a permanent tick infestation. The tufted sour grass, *Danthonia disticha*, which grows into dense wiry tussocks, and the fallen leaves of the bush, *Rhus erosa*, form suitable protection for the tick, and the tussocks also harbor the hosts of the immature stage of the ticks – the red hare and the elephant shrew. The protective cover can be destroyed by burning and may eliminate the tick for two to four years, but burning is hazardous under the slow regenerative conditions of the Karoo, although it may be done with care at certain seasons, providing stock are withheld until regeneration of the grass is well advanced. In addition, well-planned rotational grazing may improve the pasture and increase the content of the palatable grasses which offer less cover to the ticks and small mammal hosts. The absence of the sheep host during rotational grazing will also reduce the ticks through their starvation, although in the absence of the sheep the adult ticks will adapt themselves to the red hare as an alternative host.

Removal of the host

This method of environmental change is becoming increasingly applied, although the principle is not new; it was adopted by Theiler for the control of East Coast Fever at the beginning of the present century. It can successfully reduce tick numbers, and in the absence of a wild host, elimination could be achieved. In Great Britain sheep are often confined to the lowland grazings, where ticks are absent until after the spring "rise" of *Ixodes ricinus* in the hills. This is a practical procedure to prevent heavy infestation especially of the young lambs, since it only involves keeping the sheep for an extra few weeks on the lowland grazing. Milne (1945 b) concludes that this system does not appreciably prolong the tick season and that stock can run on the infested land in summer with little danger of infestation. Since the sheep is the principal host, this would reduce the tick population. Even without the intention of reducing the tick population, the practice of retaining ewes and lambs on the tick-free lowlands until the spring rise of ticks on the hills is over, greatly reduces mortality in the lambs from tick worry and tick-borne diseases. The lambs acquire very few ticks until the autumn "rise", by which time they are strong enough to withstand infection.

Portman (1945) states that *Amblyomma americanum* may be controlled in the United States by pasture management. The larvae of *A. americanum* are active from the middle of June onward in the State of Missouri and require a blood meal in order to moult and survive the winter. Keeping pastures free from stock from mid-June until after the first heavy frost for two successive years and occasionally thereafter can result in a great reduction of the numbers of ticks.

In Australia the knowledge of the limited survival period of unfed larvae of *Boophilus microplus* on pasture (Snowball 1957, Wilkinson and Wilson, 1959) has been experimentally applied to control infestations on cattle since 1953 (CSIRO, Annual Reports since 1954). Eradication of ticks has not been desired but only reduction of infestations to low levels sufficient to ensure the persistence of immunity to *Babesia* infections but not sufficient to cause tick worry. Ixodicides are still used if required but the frequency of dipping has been greatly reduced, and with increased experience it may be possible entirely to dispense with it. Reduction of the frequency of dipping greatly lowers the cost of controlling ticks and reduces the trouble and difficulty of mustering and dipping the cattle and, in future, it may be essential in order to delay the onset to resistance to ixodicides. *Boophilus* larvae have a comparatively short life of an average of about three months in summer and about five months in winter, although as Legg (1930) and Hitchcock (1955) have shown, longer periods are possible under optimum conditions. By alternate grazing in adjacent paddocks, leaving sufficient interval between the transfer of the cattle to ensure that most of the ticks in the unoccupied paddock have died, the tick infestation on the cattle can be greatly reduced. This system of pasture rotation is known as "pasture spelling," and can be easily utilized in normal grazing management and pasture improvement. Results of trials and suggested systems of application are described by Wilkinson (1957).

In Kazakhstan in the U. S. S. R., according to Galuzo *et al.*, (1958), the unfed larvae of *Boophilus calcaratus* (probably synonymous with *B. annulatus*) die after seven to eight months' hunger. Control of this species is effected by dividing the pasture in half, one half being grazed one year and the other half the following year. On farms where there are pastures which are naturally tick-free as in the mountains and deserts, these pastures are grazed in the autumn and spring when the hungry larvae are especially numerous elsewhere.

The combination of biological control with the application of ixodicides is referred to in Chapter III.

Physical and chemical methods

With the exception of subjecting ticks to unfavorable conditions of heat, cold or dryness by altering the environment, only two methods of direct destruction of ticks on the land have been attempted: (*a*) grass burning; and (*b*) the application of ixodicides.

Grass burning

Throughout Africa and other parts of the world, annual burning of grass is a common practice at the end of the dry season, to consume the dry stems and debris and to make the young grass shoots which appear at the beginning of the rains quickly available to the stock. Much of the pasture which is regularly burned is a fire climax vegetation which would revert to thicker bush in the absence of fires. It is generally accepted that this grass burning has little effect on the tick population, although, obviously, stages of the ticks which are on the grass at the time of burning will be destroyed. If grass is in a stage for burning at a time when certain stages of the tick life cycle are most active, grass burning could play a part in tick control, as has been noted earlier (Galuzo, 1944). The long-term effect of burning on the vegetation and its effects on *Ixodes rubicundus* have already been mentioned, and other tick species such as *Rhipicephalus appendiculatus* may be affected by lack of suitable cover caused by burning.

Reduction of ticks has been recorded following grass burning in Australia and elsewhere (FAO Meeting Report 1958/24) but generally the method has not been successful where it is the sole form of attack. In conjunction with the simultaneous attack on the stages on the host or by other means, however, it may play a useful role, as was noted by Smith and Gouck (1945) in their campaign against the dog tick *D. variabilis*, in which they used ixodicidal treatment of the host and of the vegetation; where accidental fires occurred when adult ticks were becoming active, there was a marked reduction in the number of ticks throughout the remainder of the season in the burned areas compared with unburned areas. There was a reasonable grass cover six weeks after the fire but the burning had a prolonged effect on the mouse population; and as the mice act as hosts for the immature stages of the tick, it was not possible to assess whether the reduction in tick population was due to direct destruction of the ticks, to the secondary effects on the vegetation, or whether it was concerned with the mouse population. It is concluded that where

there is a limited breeding cycle during the year, the destruction of one phase of this cycle on the vegetation by burning may have a serious effect on the tick population, but where the breeding cycle is prolonged or continuous, burning will destroy the ticks on the vegetation but others will soon emerge from the ground or the deeper parts of the vegetation, as was found with *B. microplus* in Australia (CSIRO, 1952), where larvae were encountered in an area 33 days after a bush fire.

The effect of the making of hay or ensilage on tick populations has not been sufficiently explored. Where survival of ticks on pasture is of long duration and pasture spelling would not be practicable, it might be possible to make good use of the grass crop as hay or silage while "spelling" it. It is unlikely that ticks would survive in ensilage, and although *B. decoloratus* can survive several weeks in hay (personal observation), it is unlikely that it could live very long, and the hay could then be safely fed to stock.

The application of ixodicides

The application of ixodicides to buildings and to limited local habitats of ticks, such as chicken runs and dog kennels, is common practice but there have been only limited attempts to kill ticks on pastures or herbage by this means. Early trials in the United States by Smith and Gouck (1944 and 1945) showed that DDT in sprays applied in amounts as low as 6 ounces per acre greatly reduced *A. americanum* nymphae for 68 days and adults for a somewhat shorter time, and at 1 pound per acre gave considerable control for at least 34 days. DDT in dust applied at 3 pounds per acre gave good control for at least 45 days. In Australia (CSIRO, 1949) spraying of a tick-infested pasture with a colloidal suspension of DDT at the rate of 1.15 pounds of p.p. DDT per acre gave practically complete control of the larval stages of *B. microplus* for 6 to 8 days after treatment, but 27 days after treatment the larval population had exceeded the original density. In the United States the trial spraying of all tracks and roadways of an island of 11.5 square miles with a DDT emulsion at the rate of 4.3 pounds of DDT per acre in May and August (Collins and Nardy, 1951) greatly reduced the numbers of *D. variabilis* during that season, and it was concluded that control of the tick in certain areas could be achieved by pasture spraying. Earlier trials had shown that gamma BHC at 1 pound per acre and chlordane at 2.75 pounds per acre were less effective in their immediate and lasting effects than DDT.

In the U. S. S. R. (Gorchakovskaya, 1955) field trials with both DDT and BHC at 4.5 pounds per acre resulted in practically complete mortality of all the adults of *Ixodes persulcatus* present in forest plots. Adult ticks did not reappear in the treated plots throughout the season in spite of the proximity of untreated forest. Similar applications to forest areas in other provinces protected forest workers from infestation.

Both the previous workers regard dusts, emulsions or suspensions of the ixodicides as equally effective.

Lancaster (1957) tried the application of similar ixodicides on trial plots of oats infested with *A. americanum*. The plots were watered, except in the summer months. Dieldrin and heptachlor at 1 pound per acre and chlordane at 2 pounds per acre usually gave a complete kill within about a week of application of the ticks, which were seeded on the plots the day after treatment.

The objective of pasture treatment has been toward the control of human disease, where the cost of control is not considered as carefully as it is in controlling diseases of domestic stock; however, it seems possible that the method could have some application in livestock husbandry, especially against tick species with a pronounced and short seasonal incidence, where one or two applications would be sufficient. It could also be applied to the disinfestation of small areas known to have been contaminated with disease-carrying ticks, or to render corridors of infested land safe for the passage of susceptible stock. It has been suggested that ixodicides might be combined with fertilizers or minerals. The timing of the application is important, in order that the ixodicide should be available at the period of maximum tick intensity. No conclusions can be reached about the adoption of this method of attack until more extensive trials have been carried out, but at present DDT appears to be the ixodicide of choice applied in amounts varying from 1 to 4.5 pounds per acre.

The principles of the application of ixodicides to buildings have been well reviewed by Davidson (1955), who notes the importance of selecting the right formulation of the chemical for the surface to be treated, the particle size of the active agent, and the need to apply the correct amount.

Ixodicides have been mostly applied to buildings to control various species of *Ornithodoros* infesting man and animals and against *Argas persicus* of poultry. *Argas* is vulnerable to attack on its host only in the larval stages. The provision of ixodicidal dusts in nesting boxes, litter and dusting sites, as is practiced for the control of lice and mites (Harding

and Quigley, 1956; Rodriguez and Riehl, 1957 b) would affect the larval stages of *Argas* but is probably insufficient for complete control of the tick, since the nymphal and adult stages are well hidden and are in contact with the birds for only short periods. Therefore, attention has been concentrated on the application of ixodicides to the resting sites of the nymphae and adults in cracks and crevices of buildings and roosting sites. Ixodicides are best applied as sprays, preferably under fairly high pressure, to ensure penetration of the crevices. In enclosed buildings, the use of smokes would seem an efficient way of penetration and success by this method has been recorded by Andreef *et al.* (1956), using hexachlorophane smoke. Published records on the use of BHC against *Argas* are not numerous but from the susceptibility of *Ornithodoros* to this compound, *Argas* is likely to respond equally well. Aldrin in 2 percent water emulsion is recorded by Edgar *et al.* (1953) and Furman and Weinmann (1956) as effecting control of *Argas*, the emulsion being sprayed at the rate of 600 to 800 milliliters per 1,000 square feet of surface. The latter authors found that malathion was effective only if ticks remained in contact with the treated surface for a long time and that well-hidden ticks could emerge unscathed; Rodriguez and Riehl (1956 and 1957 a), however, regard 1 percent malathion as being very effective in controlling the tick when sprayed onto infested surfaces under pressure of 300 pounds per square inch, in sufficient quantities to cause a run-off. Sprays of 1 percent diazinon were also effective in a limited trial.

Spraying of poultry houses with toxaphene emulsion 0.5 percent and aldrin 0.25 percent is reported by Smith (1952) to have controlled the tick, and spraying with 0.05 percent and 0.1 percent dieldrin gave promising results.

Although there is little laboratory or field evaluation and comparison of the ixodicides available against *Argas persicus*, it is evident that many of them are effective; no toxicity to fowls has been recorded following their use at effective concentrations, although actual immersion of turkeys in 2 percent or higher concentrations of malathion emulsions can be fatal to them (Furman and Weinmann, 1956).

Several *Ornithodoros* species cause irritation and blood loss to domestic animals, particularly *O. lahorensis*, which inhabit the buildings and walls where animals are housed, and *O. savigni*, which is to be found in the deep sand in desert areas, where animals commonly congregate in the shade of trees. *O. tholozani* also feeds readily on livestock and *O. moubata* may become established in pig sties.

The *Ornithodoros* species spend only very short periods on the animal host and long periods in predilection sites. Control is therefore aimed at destruction of the ticks by applying ixodicides to the resting sites. BHC preparations in the form of dusts or sprays have proved very successful in killing *O. moubata* in buildings. The quantity employed has varied greatly but the smaller amounts of 25 to 30 milligrams of gamma BHC per square foot employed in malaria control programs is certainly not sufficient. Jepson (1947) found that dusting the floor and lower parts of the walls with 0.5 percent BHC at the rate of 3 to 4 pounds per 1,000 square feet controlled the tick for nine months. Holmes (1953) found that 5 percent BHC in sawdust or chaff, spread around the base of walls, eliminated *O. moubata* for one to one and a half years. The commonest means of applying ixodicides to control *O. moubata* has been by spray, using dispersible powders or emulsions of BHC. Successful control has been achieved by quantities varying from 10 to 15 milligrams per square foot (Lovett, 1956), 300 to 600 milligrams per square foot (Annecke and Quin, 1952) and 1,250 milligrams per square foot (Hocking, 1946). The larger quantities appear to give a longer protection, since 300 milligrams protected for 12 months and 600 milligrams for at least 27 months.

It is generally accepted that DDT is less effective than BHC in killing *O. moubata* and has a shorter residual effect (Annecke and Quin, 1952).

O. tholozani has been successfully killed in mud-plastered surfaces of constructions housing stock, by spraying or dusting with BHC at the rate of 100 milligrams per square foot (Kalra and Jacobs, 1951). Babudieri (1957) notes that in Jordan, adults of this species hide under the surface of soil or humus in caves and buildings where they are protected from surface treatment, but since the ticks prefer slightly damp soil, wetting the soil with BHC solution would attract the ticks to the killing agent.

O. lahorensis is equally susceptible to BHC, and Kusov (1956) showed that 12 percent BHC dust in the cracks of stone walls of sheep enclosures killed the ticks and was still present in lethal quantities two and a half years later. For thatch or straw walls, the use of sprays of BHC suspension or emulsion is likely to be more effective than dusting. In conjunction with treating the walls and buildings, the control of *O. lahorensis* would be more rapid if the animals were also treated with a residual ixodicide, and treatment of sheep in Turkey by this means has been proposed, the fleece being parted in three or four lines down the back and the exposed surface of the skin and wool sprayed with toxaphene. Likewise, the spraying of legs of camels, cattle and equines in areas where *O. savigni* is

common would assist the reduction of this tick when combined with application of ixodicides to the ground along animal tracks and other sites where animals frequently congregate.

Several species of *ixodide* ticks spend their nonparasitic stages in localized sites associated with domestic animals, and ixodicidal treatment of these sites would be a rational means of controlling this group.

In North Africa engorged nymphae of *Hyalomma detritum* hibernate during the winter and spring in cracks and crevices of farmyard walls or under boulders in fields, the adults emerging in June or July. The application of ixodicides to the walls can play a significant role in controlling this species and is combined with killing the adult and larval stages on the animal by dipping or spraying. The seasonal incidence of these stages on the animal, adults principally in June, July and August, and larvae in late autumn, enables a concentrated or strategic dipping program to be carried out at this time.

In the U. S. S. R. the hibernation of *H. detritum* in walls does not take place and ixodicidal treatment of the environment is not applicable there. *Rhipicephalus sanguineus sanguineus* can become established in buildings, especially dog kennels and houses. The females oviposit in crevices in the walls as high as 15 feet above the ground, under stones and in cracks in the ground. Control is normally achieved by spraying with 0.05 percent to 0.1 percent emulsion or suspension of BHC, preferably under high pressure to ensure deep penetration of crevices. Neitz (1943) has described the effectiveness of pyrethrum preparation in controlling *R. sanguineus* in a kennel; and pyrethrum might also be of great value in the control of resistant strains of *R. sanguineus*, which are referred to in Chapter VII.

III. CONTROL OF PARASITES ON THE HOST

Host immunity

It has been advocated that breeds of cattle resistant to ticks should be used in tick-infested areas because they will suffer less from tick infestation, and it has even been suggested that control of tick numbers could result from this host resistance.

Host resistance of cattle to tick infestation has been reported by many observers (Johnson and Bancroft, 1938; Parr, 1924; Kelly, 1943; Bonsma, 1944; and Ullova and de Alba, 1957). It is recognized that individual animals of any breed can show a resistance to tick infestation, in that comparatively few ticks engorge on them when they are exposed to heavy and continuous infestation with the unfed stages. It is commonly believed that the zebu, *Bos indicus*, is more resistant to tick infestation than is *Bos taurus*, but there is not much experimental evidence to support this. In Brazil, Villares (1941) exposed groups of cattle of European, Brazilian and Indian breeds to *Boophilus microplus* infestation at a time of year when tick infestation was greatest. The adult ticks found on the animals were counted and measured. Of all the ticks present on the animals, 88 percent were on European breeds, 7 percent on Brazilian breeds, and 5 percent on Indian breeds. Although the European breeds as a whole carried most ticks, there were many resistant animals among them. Four of 11 Friesians had an average of 6 ticks per animal against another 4 of the 11 which had 240 ticks per animal and were classed as susceptible. Similarly, 5 of 6 of the Flemish breed had only 7 ticks per animal. The Brazilian breeds, Caracu and Mocho National were all resistant; on some animals there were no ticks at all, and they were just as resistant to infestation as the Indian breeds which, in general, had small infestations, although 4 of 11 Guzerath cattle had an average of 68 ticks per animal. In his experiments, Riek (1956), comparing the susceptibility of cattle

to *Boophilus microplus*, used 3/4 zebu x 1/4 shorthorn crossbred animals in one group and pure shorthorn cattle in another group. The 5 crossbred zebus had an average of 985 ticks each, compared with 2,276 ticks on the shorthorn cattle, when the animals were prevented from licking themselves, and 327 and 1,526, respectively, when they were not restrained from licking. As in the South American experiment there was great variation within the groups. At least one of the shorthorns was as resistant as the zebus and two of the zebus had infestations as heavy as those of the shorthorns.

Attempts to correlate resistance to ticks with the physical characters of the host, such as skin thickness, length of coat, sebaceous secretions and possible repellent effects, have not been conclusive.

The nature of the resistance has been shown by Riek (1956) and supported by other observers to involve a skin hypersensitivity with the formation of an exudate at the site of tick feeding; this exudate later forms a dried crust which mechanically kills or prevents the larvae from feeding. The skin hypersensitivity and irritation also promote licking and mechanical removal of larvae. There was some evidence of an immune reaction in the zebu which was capable of killing engorging adults.

The concept of using or developing host resistance as a means of controlling tick infestations was the subject of an investigation by a Select Committee of Parliament in Australia as early as 1915, and although this form of control was not supported by the committee, the interest in it has not been lost, as is shown by the recent work by Riek (1956). The future utilization of host resistance will first require more investigation, especially into its nature and the genetic characters of the phenomenon. It is concluded that certain breeds of cattle, such as *Bos indicus* of India and Africa have a greater resistance to tick infestation than have European breeds of cattle. This resistance appears also to exist in some South American breeds. Resistance is an inherent character which is presumably enhanced or reinforced by an acquired immunity following exposure to ticks, as Trager (1939) has shown that an active immunity can be developed by rabbits. The situation appears to be similar to that in the tick-borne diseases, where *Bos indicus*, reared in the enzootic areas of *Theileria* and *Babesia* infections, has a greater inherent resistance to these diseases than have exotic European breeds. It is, in fact, a normal parasitological climax relationship, whereby a reasonable equilibrium becomes established between indigenous host and parasite. The practical

utilization of this relationship could never be applied by itself for the extermination of the parasite. In the specific case of ticks, the employment of tick-tolerant breeds in areas where tick eradication is not desired, or where tick control by ixodicides or other methods is difficult, is desirable.

Repellents

The search for repellents effective against ticks has been directed toward the protection of human beings against tick worry and tick-borne disease. Investigation has been largely confined to the impregnation of clothing with substances which will retain their effectiveness for long periods.

Compounds or mixtures of compounds usually more directed against various insects and acarines, some of which have proved 95-100 percent effective against *Amblyomma americanum* for up to several weeks, are N butylacetanilide; 2-butyl-2-ethyl-1,3 propanediol; N butyl-4-cyclohexane-1,2 dicarboximide; undecylenic acid; 1-butyryl-1,2,3,4-tetrahydroquinoline; indalone; diethyltoluamide; dimethylpthalate (Smith *et al.* 1954; Gouck and Gilbert, 1955; Smith, 1958; Smith, Gilbert and Gouck, 1958). It is not known whether such compounds would be equally effective when applied to animals or when used against other species of ticks.

The search for an effective and low-cost repellent for use on livestock appears to be a worthwhile objective since, theoretically, the ideal repellent could replace an ixodicide. It is improbable, however, that the best repellent will be as good as the best ixodicide. There is need for a good repellent to protect susceptible stock when passing through areas where there are ticks and tick-borne disease, since ixodicides may not kill the vectors of disease before they have had time to attach and transmit infection. Mulhearn (1956) notes the problem of marketing cattle from the tick-free areas of Queensland at the principal consuming areas, which are tick-infested. At the present time, stock must be slaughtered within eight to ten days (the incubation period of *Babesia* infection) to avoid losses. Similar difficulties are encountered in Africa, where stockowners are forced to graze susceptible stock in tick-borne disease areas in the dry season, when there is no grazing in the tick-free areas. A minor but valuable protection could be given to horses and dogs used for sport and exposed to danger from ticks or disease during short periods.

Application of ixodicides to the host

The objective is two-fold: firstly, to protect the animals from the mechanical, toxic or disease-transmitting injury of ticks by killing them as soon as possible after they have gained access to the host; and secondly, by employing animals as bait to collect the ticks and then to take them to a tick-killing bath and thereby, in the course of time, to reduce the numbers of ticks present on the pastures or entirely to eradicate them.

The well-established method of applying the ixodicide is to wet the animal with a solution or suspension of the chemical by spraying or immersion in the fluid. Other methods, such as dusting and fogging, have not been extensively employed but their use is discussed here.

Dusting

The ixodicide is applied in the form of a fine powder, usually diluted with some inert substance. This form of application has been extensively employed for the application of insecticides to domestic pets, especially cats, to control fleas, and to poultry for the control of lice and mites. The self-dusting habits of poultry make this method of application particularly suited to birds, where a continuous application of the insecticide is ensured. In general, dusts are not very efficacious against ticks on animals because of the rapidity with which the powder is lost from the body and the difficulty of ensuring that it covers the whole surface and comes into intimate contact with the parasites. Dusting might have some advantage over the use of fluid preparations in the long-wooled sheep, where it is difficult to wet the fleece thoroughly and where there are objections to wetting these animals in winter and also in areas where water supplies are difficult or uncertain. There are difficulties in applying dusts to large numbers of sheep but Hiepe (1956) described a method of applying them with a spray gun connected to a compressed air supply, and he was able to treat 75 to 150 sheep per hour. A portable dusting machine has been produced commercially in the United States, which is claimed to treat sheep more rapidly and less expensively than dipping or spraying. At one time it was used fairly extensively in New Zealand. It is not certain how efficacious dusts are against sheep ticks but the sheep ked has been experimentally eliminated by this means by Pfadt and Defolliart (1957), who found that 1.5 percent dieldrin was the most effective compound. Less effective dusts were 1 percent dieldrin, 5 percent chlordane, 5 percent

toxaphene, 1 percent heptachlor, 1 percent lindane and 0.5 percent rotenone. It seems possible that the tick worry caused by *O. lahorensis* in the winter-housed sheep in the Near Middle East could be controlled by dusting the sheep with dieldrin powder in conjunction with treatment of the buildings.

It is unlikely that powders will be as effective as wetting compounds in the treatment of cattle.

Fogging

The insecticide is introduced as an atomized spray into a blast of hot or cold air where it is further fractionated. The hot blast is also called a thermal aerosol. Various methods of fogging have been tried for tick control and all have proved expensive and inefficient.

Dipping baths

Where comparatively large numbers of animals are involved, treatment by immersion in a dipping bath has been the most favored method of applying ixodicidal fluids to livestock for many years. The essential requirements for good dipping are described for convenience under three headings: (*a*) the approach section; (*b*) the swim bath; and (*c*) the drainage section. Each class of stock requires its own particular type of bath, and therefore cattle and sheep baths will be discussed separately. The structure and the physical management of baths form part of this chapter; the dipping agents employed are dealt with in Chapter V.

Cattle-dipping baths

The siting of a bath requires careful thought in order to combine or compromise between all the desirable requirements. Water must be freely available and, if the expense of pumping water over long distances is to be avoided, the tank must be near a stream or dam. The site should be central to the cattle-grazing area, so that the animals do not have to walk long distances. Permanent approach and departure roads, preferably contoured, are desirable, for the constant trampling by cattle can easily cause gully erosions around the dip. Low-lying ground which may be flooded should be avoided. The soil and subsoil should be tested before commencing digging operations, as rock may interfere with digging, and

special construction may be needed for certain types of soil such as heavy clay, loose sand, and black alluvial soils, which predispose to cracking of the walls of the dip. It should be remembered that a slope is needed for the different parts of the dip and that it may be possible to utilize natural slopes at the site and save the cost and labor of making them artificially.

The approach system consists of a collecting yard, an approach race, preferably provided with a foot bath, and a take-off ramp.

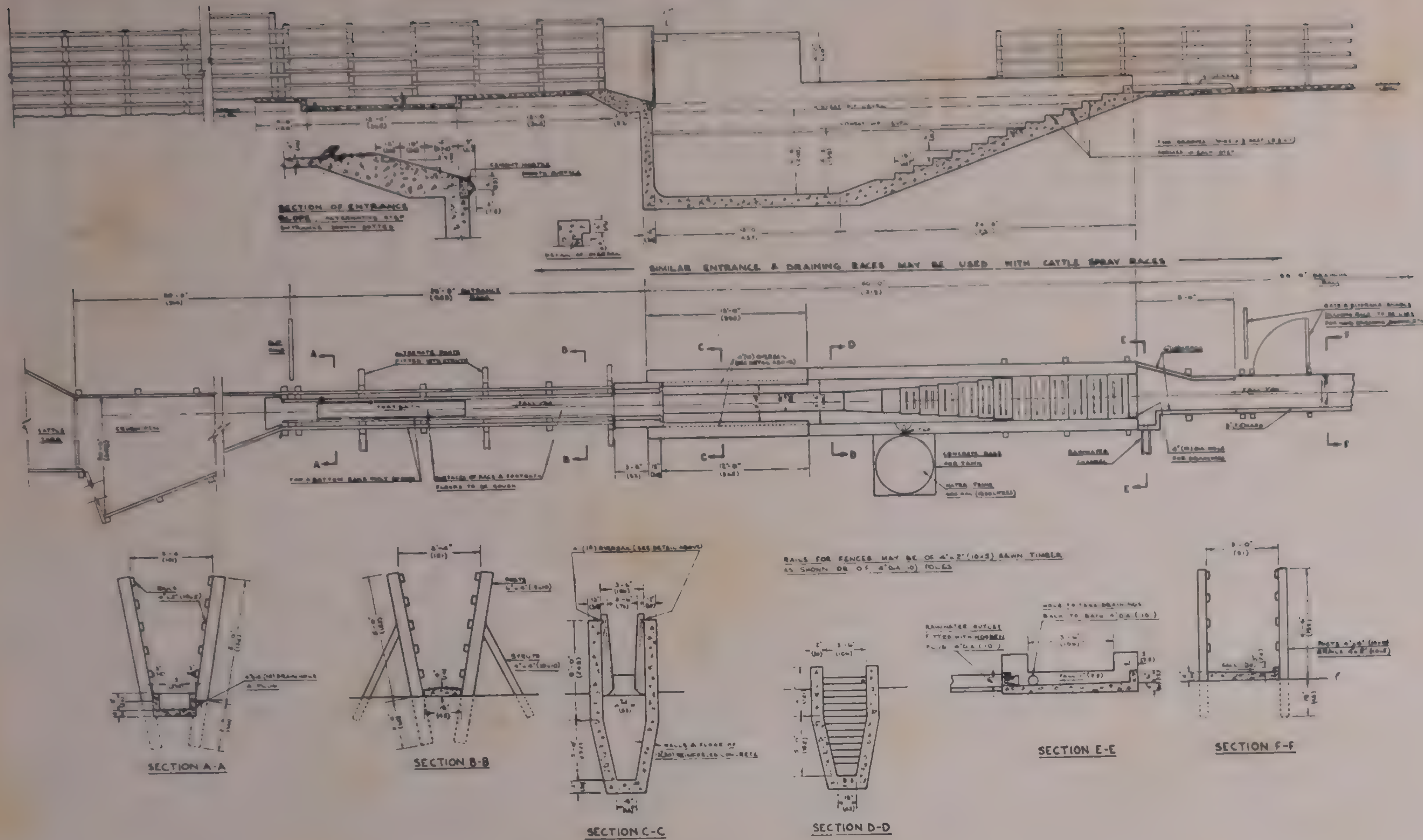
The collecting yard normally holds from 50 to 70 cattle and is best made in a rectangular shape with the narrow side adjoining the approach race and narrowing down to it in a long funnel. If the collecting yard is too large and square or the funnel too short and wide-angled, the cattle can circulate round and round the yard and never enter the race. The walls of the yard need to be made of heavy posts and cross-poles. The floor should preferably be paved with stone or rough concrete to avoid the trampling of mud and manure into the dip in wet weather. The approach race should be about 25 feet (760 centimeters) long, and provision for slip rails should be made at the entrance and exit, so that cattle movement can be halted, if necessary. A foot bath, 12 feet (365 centimeters) or more long and 8 inches (20 centimeters) deep, is set into this race. It is best to have water running through the foot bath when the cattle are muddy, but in any case a large drainage plug should be provided, so that the water can be quickly changed when it gets badly fouled. If water for a foot bath is not available, the approach race should be longer and have a rough, cobbly surface, so that mud is shaken onto the ground. The floor of the approach race between the foot bath and the entrance to the bath should slope upward, toward the bath, so that rain water and water from the foot bath will drain away from the tank. The take-off section is enclosed with an extension of the dip walls, which should be at least 6 feet (185 centimeters) high, so that the animal can only see the bath ahead and will not attempt to rear upward or sideways. The length of the enclosed take-off section should be about 4 feet (120 centimeters), which allows the animal to be urged from the rear if it attempts to turn or refuses to jump. The floor of the take-off section should slope toward the dip, and most people prefer it to have a series of three or four shallow steps leading down to the lip of the tank, to provide purchase for the animals to take-off. If steps are not provided, the slope should be rough-surfaced, to prevent the animal from slipping and falling awkwardly onto the lip or sides of the bath. The edge of the take-off should project over

the end of the bath for 3 inches (7.5 centimeters) in the form of a lip, which reflects the surge of water back into the dip. The top of the lip should be smoothly curved.

The swim bath must be long enough to allow for the forward jump of the animal without its hitting the exit steps, and to give it a reasonable time for immersion. A long swim was formerly provided to ensure thorough wetting but now that modern dip fluids contain wetting agents, it is considered that, providing complete immersion takes place and the whole body of the animal is wetted, there will be adequate penetration of the hair and body surface. Animals can be deterrred from jumping far forward by hanging a sack down from one of the crossbeams of the roof, about 8 feet (245 centimeters) in front of the take-off point. The length of the bath should be made as short as possible, in order to reduce construction and maintenance costs, but the horizontal floor should never be less than 15 feet (460 centimeters) long. Such a bath has a capacity of about 3,000 gallons (13,530 liters), which is adequate for dipping several hundred head of cattle. There are some advantages of larger baths for very large numbers of cattle, in order to avoid stoppages in dipping for the purpose of topping-up the fluid or replenishing chemical ingredients. Even large herds usually run in smaller mobs and it is unlikely that these will be presented continuously, so that there will be intervals for attending to the dip fluid, and it is not really essential for large herds to have a larger bath. The capacity of a bath can be increased only by increasing the length, as the width and the depth can vary only very slightly from the dimensions given, if the dip is to function efficiently.

The depth from below the lip to the bottom of the tank should be about 7 feet (215 centimeters). This allows for a fall in fluid of about 18 inches (45 centimeters) during the course of dipping, before the depth of the water becomes too shallow for safety and for proper immersion. The tank need not be more than about 3 feet 6 inches (105 centimeters) wide at the water surface, unless exceptionally long-horned cattle are to be dipped. About 5 feet (150 centimeters) from the bottom, the walls slope inward, so that the width at the bottom is about 18 inches (45 centimeters). The guide plan in Figure 1 shows a vertical wall below the jumping-off point and has a small rounded junction with the floor but there is a trend toward filling in this end of the dip with a concrete wedge, starting about 3 feet (90 centimeters) high at the take-off wall and sloping downward to meet the bottom of the dip at about 5 feet (150 centimeters) from the take-off wall. This is done because there is a dead space here

FIGURE 1. - Cattle-Dipping Bath



which fills with silt and adsorbed chemical, and this silt deposit never becomes agitated unless stirred out with a shovel. Graham (1956) suggests that the deposition of ixodicide in this area accounts for the fall in strength in dip wash during the first few dippings in a freshly charged tank. Provision of the wedge allows effective scouring and mixing of the whole dip fluid, especially the dip floor.

The exit slope of the bath should be at an angle of about 20 degrees and its floor stepped, with intervals of about 9 to 18 inches (25 to 50 centimeters) between the steps and the height of the steps from 4 to 6 inches (10 to 15 centimeters). The surface of the steps should be grooved or roughened and their edges rounded. Steps are better than the roughened slope which is sometimes used, for the steps break the splash waves and prevent excessive surging of the fluid during dipping.

At the entrance to the bath the walls should be at least 6 feet (185 centimeters) above the surface level of the dip fluid and should extend 10 to 12 feet (300 to 365 centimeters) along the sides, to prevent loss of dip from splashing as the cattle plunge in. A catwalk is essential along one side, and in some dips it is made along both sides. The catwalk is best continued along the whole length of the dip, so that there is easy access to animals in difficulty. In this case the splash wall should be put on the outer side of the catwalk and a drainage channel provided on the floor of the catwalk to run splashed dip fluid back into the dip. It is also necessary to make a small protective wall at the jump-in end, to prevent cattle from jumping onto the catwalk, but it should be short enough so that there is no hindrance in handling animals which have swum back to the entry point.

The swim bath should be roofed from end to end to prevent dilution of the dip fluid with rain water or loss of water from evaporation. The roofing materials can be simple and cheap but it is best to provide a surface which can collect rain water, which is led to the reservoir tank at the edge of the dip.

Baths may be constructed of brick, stone, reinforced concrete, prefabricated iron or steel or even wood, depending on the cheapest source available. In general, reinforced concrete is the most satisfactory and gives the least trouble from cracking and leaking. Whichever material is used, the construction is a skilled job and is best not attempted by amateurs. Prefabricated iron or steel tanks are probably the best when skilled labor is not available, especially where regional dipping schemes are initiated and large numbers of tanks have to be erected, or where

quarantine measures have to be quickly implemented and the tank is needed at a particular site for only a few months. Much of the material can then be salvaged and used elsewhere. The exit race must be long enough to allow all surplus wash to drain from the dipped cattle; a length of 80 feet (24.5 meters) is desirable. A double exit race can be made with a swing door at the exit slope, so that cattle leaving the bath can be directed into one or other of the races. The double race is much shorter, since the animals are usually held in it by a gate or slip rails while hand dressing or other attention is given to them, and to allow drainage or wash to be completed before they are released.

The double or single exit race is often used as a crush for carrying out inoculation operations at times other than dipping, and a gate can be provided at the beginning of the race, so that cattle can enter or leave without passing through the dip tank. Raised catwalks and slip rail points along the exit race facilitate handling of cattle by inoculators or hand dressers. The floor of the race should be made of concrete, with a slope toward the dip bath, and a rough or grooved surface. The floor surface may slope inward toward the center, or toward one side, and there should be a drainage channel running down the lowest point, to canalize the water running back to the dip. The side channel makes it somewhat easier to sweep off dung after dipping has finished, and in this case a curb, 3-4 inches (7.5-10 centimeters) high is provided down the outer edge, to contain the fluid draining back to the dip.

In all drainage races a curb 6 inches (15 centimeters) high should be provided on each side for a distance of 10 feet (300 centimeters) from the junction of the exit slope, and this curb should continue across the top step of the exit slope to form a barrier to prevent fluid running directly into the bath and to direct it into a sump. The sump has two exits, either of which can be closed with a simple plug of wood or with sacking. One exit runs directly back into the dip, and the other to a water drainage sump or drainage channel. When cattle are being dipped, the exit to the drainage channel should be closed; at all other times the opening into the bath should be closed and the drainage channel open, to prevent rain water from the drainage race entering the dip. The structure of the sump is the subject of some controversy. Some people believe that the dip fluid draining from the animals should pass through a filter or settling tank before it returns to the dip. If the top of the sump is covered with wire mesh or perforated metal having holes about $^{3}/_{16}$ inch (4.5 millimeters) in diameter, the coarse particles of hair, grass, etc., will be retained on the

mesh; but the bulk of the contaminant is feces of small particle size, and a filter which would retain such particles would clog so rapidly that it would constantly impede the return of fluid to the tank. A settling tank can be used, the fluid flowing in at the top of one side and out at the top of the other side, and a baffle or baffles, hanging across the center and reaching nearly to the bottom of the sump, should direct the flow under it. Suspended particles settle at the bottom. Given a sufficiently slow flow and an adequate baffle system, it would be possible to separate out the bulk of the feces particles, but it is doubtful if even the very large sumps used in some tanks settle out more than a small fraction of the suspended matter from the rapid flow which occurs at dipping time. Apart from the practicability of removing feces particles, there is doubt about the desirability of removing them, because much of the active agent in suspension or emulsion dips becomes adsorbed onto these fine particles. This adsorbed chemical is still available as ixodicide if it returns to the dip, but if it is settled or filtered out it will be discarded and result in an unnecessary loss of ixodicide. There is a growing tendency today not to employ a settling sump but simply to have a shallow sump which acts as a two-way valve for diverting fluid to the tank or to the outside drain.

A well-fenced dispersal yard to contain each mob of cattle after dipping should be provided.

Auxiliary structures for the bath should consist of a water tank containing at least 500 gallons (2,250 liters) for topping-up the fluid level of the bath, and a soakaway pit into which fluid from the bath is emptied or pumped when the bath needs cleaning. This pit is most essential when arsenical fluids are used, and it should, as well as the whole area of the dip, be surrounded by a stock-proof fence. A storeroom in which the dip concentrates and equipment used in dipping and dip-testing can be stored securely should be built close to the dip; a drinking water supply should be provided near the entrance pen.

Before a dip is used it must be accurately calibrated to the nearest 50 gallons (225 liters) by filling it from a container of known capacity. Calibration may be by permanent marks on the walls of the tank or by marks on a dip stick. There is some objection to using a stick which rests on the bottom of the tank, as silt deposits may prevent the stick from resting on the concrete. A T-shaped dip stick is preferable: the horizontal bar rests across the dip walls and the calibration is made on the vertical bar which hangs down in the dip fluid. The new tank should be left filled

with water to saturate the walls and to check for leaks before the ixodicide is put into it.

In hot countries dipping is carried out in the early morning. This enables the cattle to be mustered without their becoming hot and tired, and it ensures that after dipping they will not be exposed to hot sun, which predisposes to skin damage and toxicity, especially if arsenic is used. Heavy rain can wash off much of the dip if cattle are exposed to it before the dip has had time to dry on them. In countries where short-interval dipping is essential, it is not possible to postpone dipping for a whole day because of heavy rain but it may be possible to delay it for a few hours. For the same reason, cattle should not be allowed to wade in dams or rivers after dipping.

Adequate manpower must be available on dipping days to ensure a continuous and even flow of cattle through the dip. A strict drill or routine must be adhered to, and each man must be aware of his responsibilities. The dip strength and volume can be adjusted either before or after dipping but it is usually done before. The volume is checked, and if a dip analysis is available, the strength is adjusted and the volume corrected. In the absence of dip analysis, the strength is calculated from the number of animals last dipped, and for this reason it is essential that a record book be kept at the dip and all details relevant to the dip entered in it.

Samples for testing the strength of the dip are always taken when the last few cattle are passing through; the method of sampling is given in Chapter VI. If a vat-side test is available, it is convenient to test and adjust the dip after dipping has been completed.

Before passing the cattle through, the foot bath should be checked and, if running water is available, it should be turned on. The outlet hole from the draining pen should be opened into the bath and closed to the outside exit drain.

Thorough stirring of the dip must be carried out. Some people advise stirring with long shovels or paddles, followed by the passage of a number of cattle; others depend on cattle alone for stirring. At least 25 head of cattle should pass through the dip to stir it, and in large baths, up to 50 are necessary. These "stirring" animals are usually old oxen, which are calm and well accustomed to the dip, but any large animals may be used. Having passed through, they are returned to the herd and dipped a second time in the properly stirred fluid.

The cattle may then be dipped, after having ensured that they are rested and watered. They should pass through the dip in their age groups and not as mixtures of small and large animals. If hand dressing is carried out, it is usually done when the cattle are in the drainage pen, at which time the animals can be inspected for injuries and the presence of ticks and, if needed, they can be treated or inoculated.

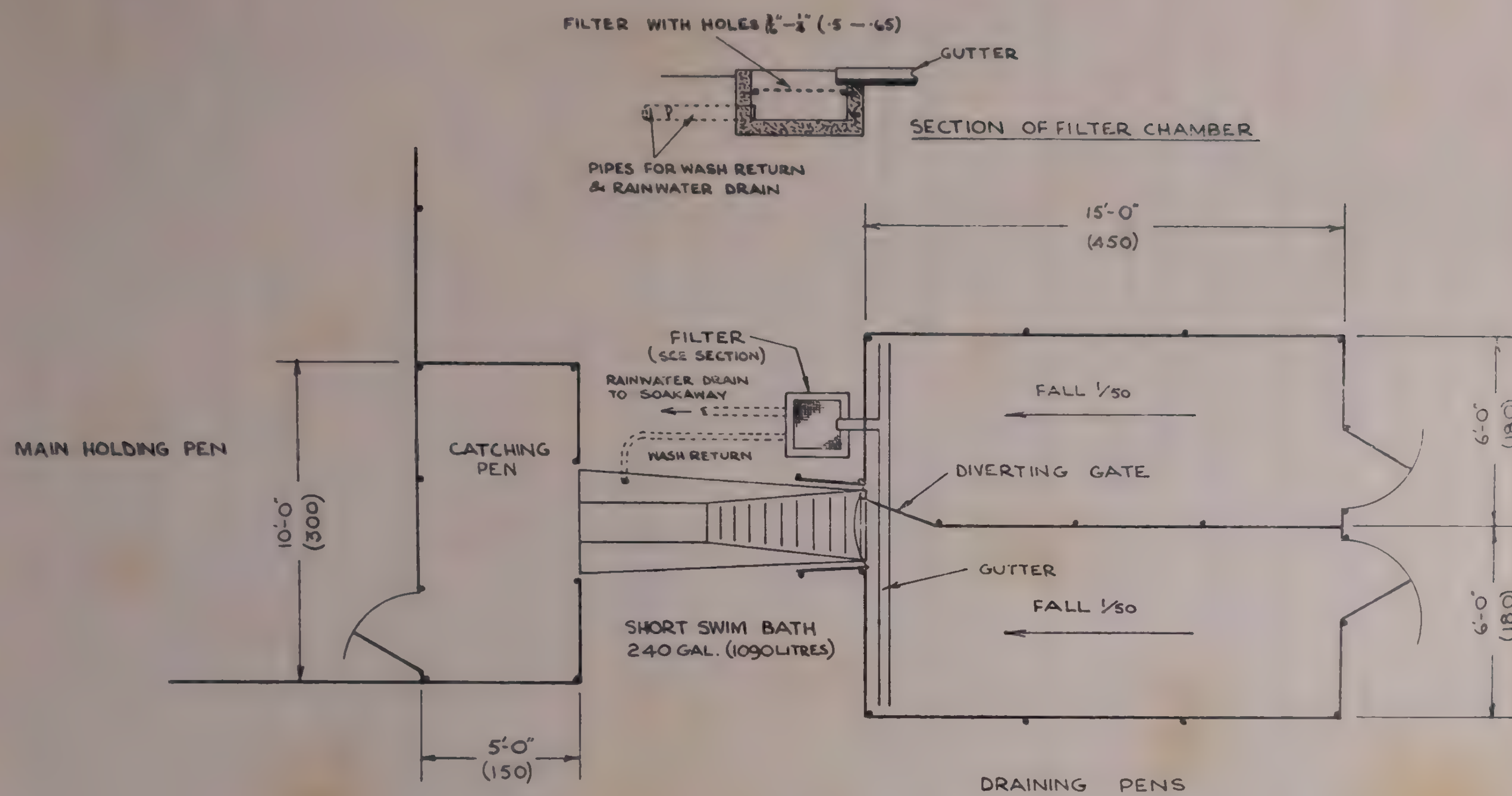
After dipping, the approach and exit systems should be cleaned, the catwalk brushed down, and the foot bath emptied and cleaned. The sump from the draining pen should be cleaned, the exit hole to the dip closed, and that to the outside drain opened. Scum should be skimmed off the top of the dip fluid. Arrangement of catching and drainage pens is shown in Figure 2.

Sheep and goats are normally dipped less frequently than cattle and more with a view to the control of ectoparasites such as mites than ticks. While sheep are mustered for dipping, other operations, such as worm dosing, foot paring, ear tagging, vaccination, etc., should normally be carried out, so that the dipping bath may have a number of ancilliary pens and races built around it to enable these other operations to be done.

Because of their small size, sheep and goats can be lifted and handled individually. This enables very simple baths to be used for dipping small numbers of them; if they are to be immersed like cattle, however, the same sized bath for one as for 100 animals is required.

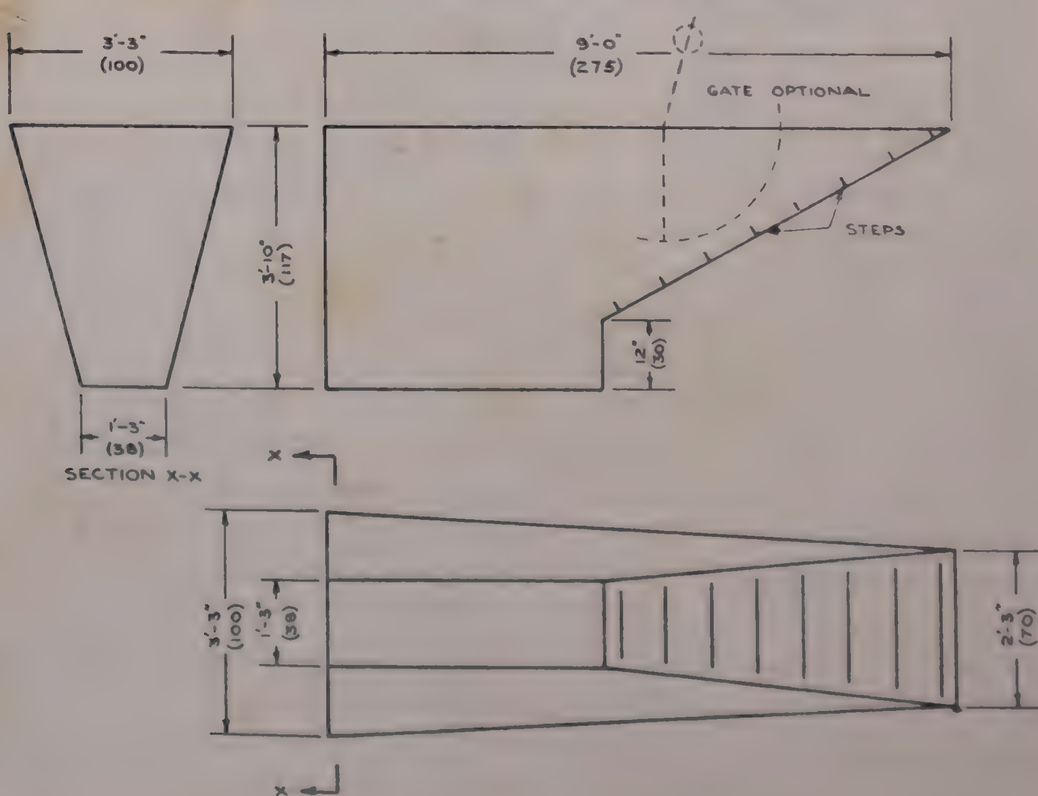
For small sheep and goats, half an oil drum mounted on some support is quite adequate for treating a few animals. A complete oil drum, sunk in the ground, is better, and fresh dip fluid contained in another drum standing near can be used to top up the drum bath if a number of animals are being dipped. Various elaborations can be developed from this nucleus, such as simple collecting and drainage pens made from sticks; a concrete skin can be put over the packed earth floor of the draining pen, and if a few holes are made in the top of the oil drum bath where it projects a little above the ground, the return wash can be collected.. Similar but slightly more elaborate dips are often constructed on a community basis, the tank consisting of a galvanized iron tank or a brick-built, concrete-surfaced tank holding 150 to 200 gallons (700-1,000 liters). These tanks may be above or below ground and do not usually have a drainage pen for the return of dip wash, but there is often a small platform on the outlet side of the tank on which the sheep stand for a few moments before being lifted off. In Africa and elsewhere, many of the animals can be easily lifted and carried, but for large numbers of the heavier breeds an exit slope is needed.

FIGURE 2. - Arrangement of Catching and Drainage Pens



A common type of small bath which will handle up to 300 animals is illustrated in Figure 3. It can be constructed with local materials such as brick, stone or concrete, and the inside faced with cement, or specially designed galvanized iron tanks can be purchased. The tank is entirely or partly sunk in the ground and a catching and draining pen are constructed at each end. The catching pen should measure 7 × 5 feet (215 × 150 centimeters), the longer side being across the end of the bath and level with the top of the bath. An opening in the wall of the catching pen allows the handler to lower the sheep with its hind legs first and with its back to the handler. A rubber or wooden roller along the edge of the bath aids entry and minimizes injury to the animals. If a roller is not used, the edge of the bath should be smooth and rounded. The sheep are restrained in the bath for 30 to 60 seconds and their heads are well wetted by immersion, which is done by an operator standing at the side with a wooden crutch. A walk-out ramp is provided to enable the sheep to leave the bath unaided. A swing-out gate controlled by a lever, operated by the man handling the dipping crutch, is sometimes provided but it has not proved efficient in practice. As with cattle-dipping baths, the tank should be accurately

FIGURE 3. - Short Swim Bath for Sheep



calibrated in units of 20 gallons (100 liters) when the tank is first filled. A single or double drainage pen measuring 12×7 feet (365×215 centimeters) with a concrete floor and a slope back to the dip tank enables dip wash to be re-used. Coarse filtration of sheep wash is essential and a shallow sump covered with perforated metal and having holes about $^{3}/_{16}$ inch (4.5 millimeters) diameter will remove pellets and wool from the fluid. Another method is to have a deeper sump into which is put a loosely fitting metal bucket having perforated holes all round its sides. The fluid flows into the bucket and out through a hole in the bottom of the sump, the solids being left in the bucket, which can easily be lifted out and emptied during the course of dipping or when dipping is completed. As with the cattle dip, two exits are made in the sump: one leading back into the dip, and the other to an outside drainage channel or sump. Some tanks are made with a drainage hole at the bottom of the tank for easy emptying and cleaning. It is convenient to provide tanks which are above ground with a pipe and stopcock outside the tank to drain them; but with sunken tanks, a second sump, as deep as the dip tank, must be sunk near the tank. The pipe leading out of the bottom of the tank passes through the sump and, at this point, a stopcock is fitted to the pipe. Types of taps and valves inside the tank and operated by levers from the top are not satisfactory.

For large flocks of sheep, a long swim bath is needed and it is not usually possible to handle large numbers individually. More subtlety is needed to make sheep enter a bath by themselves than with cattle. As has already been said, there is often a fairly elaborate system of pens for handling and treating the sheep prior to dipping. From these pens an approach race leads to the dip, at right angles to it, so that sheep do not see the dip until the last moment. The floor of the race is composed of rough concrete or is slatted with battens and slopes upward toward the dip, because sheep prefer to go uphill. The race turns at right angles into the entry point of the dip. There are several methods of forcing the sheep to enter the bath. A jump-in entry similar to that for cattle is common but instead of having a firm jumping platform, there is often a slippery slope down which the sheep slide to the plunge entrance to the bath, or the slope may be below the surface of the water, so that the sheep do not know it is there until they have lost their foothold. The entrance to the bath is 3 feet 6 inches (105 centimeters) wide to allow two sheep to enter simultaneously, but after 10 feet (300 centimeters) it narrows down to 2 feet (60 centimeters) wide. It is 30 to 45 feet (915

to 1,370 centimeters) long to allow at least 30 seconds immersion while the sheep swim through it. The depth is 5 feet (150 centimeters) and the width at the water surface is 2 feet (60 centimeters), narrowing down to 9 inches (25 centimeters) at the bottom. The capacity of such a bath, 45 feet (1,370 centimeters) long at the water surface, is 2,000 gallons (10,000 liters). In the direct plunge entry tanks, there should be side walls at least 3 feet (90 centimeters) high and extending 10 feet (300 centimeters) along the edges of the tank, to prevent sheep from jumping over the side and to stop splashing. The exit slope should not exceed 25 degrees, as the fleece of dipped sheep holds much water and the sheep have difficulty in climbing out. The floor of the exit slope must have bars or battens on it at short intervals. The width of the exit slope should increase from 9 inches (25 centimeters) at its base to 3 feet 6 inches (105 centimeters) at the surface.

The exit slope leads to the drainage pens, of which there are usually two and which are much larger than for the short swim bath; a swing gate at the entrance allows them to be filled and emptied alternately. Each pen normally holds 20 to 30 sheep and 4 to 5 square feet (120-150 square centimeters) are allowed per sheep. The sheep must be allowed to drain for at least five minutes. The floor of the pen should be made of concrete and should slope toward the tank. Sheep in full fleece may remove as much as 5 to 10 gallons (25 to 50 liters) of wash, most of which will drain off, so that the sump provided with a filter and return pipe should be large enough to deal with a considerable flow of fluid.

The long swim bath with a walk-in entrance may be used as a shallow walk-through bath which will wet the legs and underparts of the sheep without wetting the whole fleece. This type of bath may be designed as a walk-through bath only, with a depth at water level of 18 to 24 inches (45-60 centimeters). It is a type of bath commonly used in Africa to control tick species which are predominantly on the nonwooled surfaces of the sheep. Its use prevents possible injury to the fleece and the animals, since they will fairly readily accustom themselves to walking through it voluntarily, and it also needs less dip fluid to keep it filled.

There are other designs of tanks for dipping large numbers of sheep for which a smaller volume of fluid than in the long swim bath is required. The circular ring bath provides the advantages of the long swim bath, costs less to construct and requires less fluid. It consists of a circular well, in the center of which there is a circular island. The moat is filled with dip fluid and the sheep are introduced to it either by hand or by a side-

delivery entrance race. They swim several times round the bath, being controlled by a man standing on the central island who immerses their heads with a wooden crutch and who can direct the sheep out of the bath through a gate on the periphery, which he can open by means of a handle. The exit ramp and drainage pens are of the type used in the long swim bath. The width of the swimming circle is 2 feet 3 inches (70 centimeters) at the surface, narrowing down to to 1 foot 4 inches (40 centimeters) at the bottom. The depth of the fluid is 4 feet 6 inches (140 centimeters); the diameter of the island is 3 feet 6 inches (105 centimeters). Such a bath holds 800 to 1,000 gallons (3,600-4,500 liters).

Another type of bath known as the "pot" bath is either round or rectangular in shape but has no central island. Several sheep are introduced, either by hand or through a side-delivery race or tip platform. They swim in the bath, while being contained in it by a check gate at the bottom of the exit ramp. When they are sufficiently wetted and the heads have been immersed by an attendant with a crutch, the gate is opened and the sheep are directed up the exit ramp. The bath holds 600 to 1,000 gallons (2,700-4,500 liters) and the internal measurements are 7 feet (200 centimeters) long, 5 feet (150 centimeters) wide and about 5 feet (150 centimeters) deep.

Mechanical or self-entry into the plunge baths or the pot dips can be effected through a side-delivery entrance race or by a tip platform. In the side-delivery form the entrance race runs past the end of the tank and at right angles to it, and appears to continue past it, for on the far side of the tank there is a narrow pen of decoy sheep. The side of the entrance adjoining the dip has sacking suspended from a top rail and the floor at this point is steeply sloping and smooth, so that sheep, endeavoring to walk toward the decoy sheep, slide sideways into the dip. The tip platform is a small enclosure of wood to hold up to six sheep, into which the sheep are driven from the entrance race. The floor and side wall adjoining the tank are hinged and a lever system operates both floor and walls, so that the floor hinges downward and the side wall opens outward and upward, and the sheep are dropped out into the bath. One man is needed to drive the sheep into the tip platform and one man can eject and immerse them and open the exit gate. The tip platform allows rapid and easy handling of large numbers of sheep but care must be exercised in operating the platform, and the surfaces must be kept smooth to avoid injuries to the sheep. When tipped down, the edge of the floor should be level with the dip fluid.

The large tanks may be emptied mechanically or by hand-operated pumps or, alternatively, they may be equipped with a drainage outlet.

The general considerations as to siting and auxiliary equipment discussed under cattle dips apply also to sheep dips.

The dipping of equines

Horses can be accustomed to pass through a cattle dip but the first few dippings can be exciting, and there is always a risk of injury to the animals. In normal circumstances, spraying or swabbing with ixodicide is preferred.

The dipping of dogs

Most owners of dogs dip them in a household container such as a small tin bath, but with the larger breeds it is sometimes difficult to provide a sufficiently large bath of adequate depth. There is a considerable amount of labor in ladling dip fluid over a large dog. In many breeds the coat is very resistant to the penetration of fluid, which must be well worked in with the fingers, in order that the dip may reach the ticks on the skin. The head and ears and between the toes are favorite sites for tick infestation and they must receive special attention. In countries where ticks and other ectoparasites are numerous and where weekly dipping is necessary, a large communal bath, operated and maintained by the municipality or a canine society, is a great asset. It can be constructed of concrete or galvanized iron and should measure 3 feet 6 inches to 4 feet (105 to 120 centimeters) long, 2 feet (60 centimeters) wide, and about 2 feet 6 inches (75 centimeters) deep.

The dipping of camels

Treatment of camels for infestation by ticks and other ectoparasites is normally done by spraying, but the Libyan-American Joint Services Project has described a dipping bath which has been constructed and used for immersing camels. It is 65 feet (20 meters) long, 8 feet (2.45 meters) deep, and 5 feet (1.50 meters) wide at the top, narrowing down to 4 feet (120 meters) wide at the bottom. Its capacity is 13,300 gallons (60,400 liters). It has been used to control ticks, mange mites, lice, fleas and flies, and a BHC emulsion has been used as the acaricide. Considerable difficulty has been encountered in getting the camels, especially the large bull camels, to enter the dip but the results of the treatment have been

good. This appears to be the only camel dip in existence and, to that extent is experimental, but blueprints detailing its construction may be obtained from the Libyan-American Joint Services, Livestock Department, c/o American Embassy, Tripoli, Libya.

The dipping of buffaloes

Treatment of buffaloes to control ectoparasites is sometimes necessary. Acaricides are usually applied by swabbing or spraying with a hand spray. One of the difficulties of treating buffaloes is their need for frequent immersion in wallows, which washes off the acaricide. It has been suggested that small wallows could be used, in which a suitable concentration of acaricide could be incorporated, thus acting as a voluntary dip.

SPRAYS

The application of fluid acaricide to an animal by means of a spray has many advantages, and using the modern insecticides, the method has been widely and successfully practiced for controlling ticks on most of the large domestic animals. The ixodicidal fluid is freshly made up in the correct strength for each application and the quantity made up needs to be very little more than is actually used on the animals, so that wastage is small. The equipment needed can be cheap to buy and simple to operate where only small numbers of animals are to be treated, since the spray pump can be manually operated. The disadvantage of manual operation is that the application of ixodicide is only as efficient as the operator cares to make it, and since thorough wetting of large animals is laborious, regular treatment may not receive the required attention.

Mechanical systems of spraying have been designed to ensure that if the animal passes through the system it will be completely wetted. These systems need to be power-operated, because a large volume of fluid is continuously circulating. A series of pipes with nozzles in them is arranged to form a tunnel of spray through which the animals walk. The arrangement of the pipes and the numbers and types of nozzles have been, and still are, the subject of considerable experimentation. The present trend is toward shorter tunnels than in the earlier types, and has reached its ultimate limit in the form of a single ring of piping with large output nozzles which form a single sheet or wall of fluid. Spray units may be purchased, ready for erection, and these commercial units have usually been tested for efficiency for long periods before they are marketed. The

power-operated spray is cheaper and simpler to construct than a dip but its running costs are higher. It is completely dependent on the proper functioning of the engine and pump, and in short-interval dipping, where precise days of treatment are essential, it is desirable that adequate spare parts should be kept on the spot.

The wetting of animals in a spray is a more gentle operation than immersing them in a plunge dip and can also be more rapidly carried out. Equines can be more safely put through a spray than a dip.

The changeover to a different type of dipping agent is easy and inexpensive, and the problems of contamination and deterioration which occur in dips do not have to be considered with sprays.

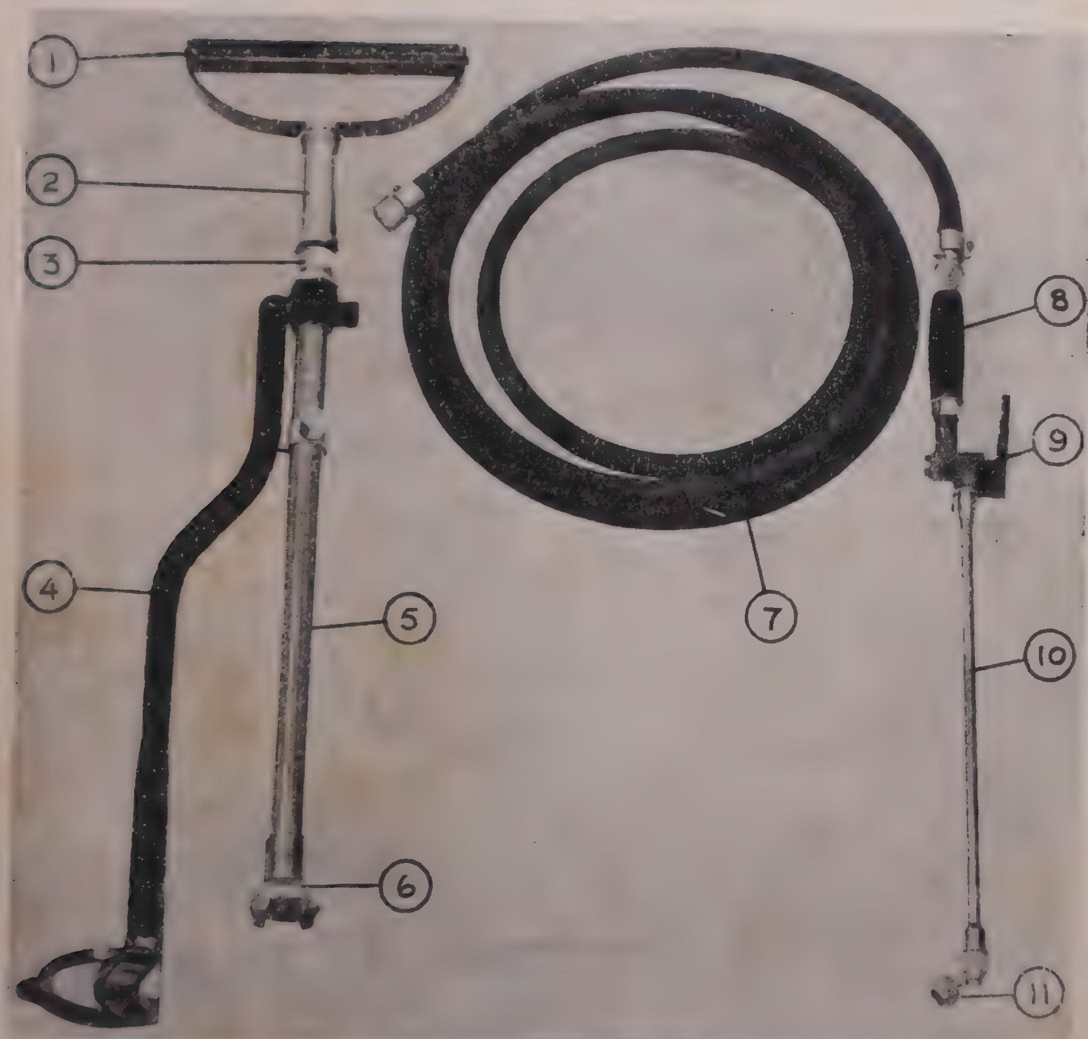
Commercially-produced sheep sprays are widely used for the control of blow-fly, keds and lice, but they are not generally recommended for the control of ticks.

Cattle sprays

The simplest spray mechanism for treating small numbers of cattle is the bucket pump illustrated in Figure 4.

These pumps can be purchased; they should be cheap, robust and simple to operate and maintain. They achieve their effect of thoroughly wetting the animal from a high pressure of fluid from a small nozzle, because they can deliver only a small volume of fluid. They should therefore be capable of maintaining a steady pressure of 80 to 100 pounds per square inch and of delivering $^1/_2$ to $^3/_4$ of a gallon (2.5 to 3.5 liters) of fluid per minute in a steady flow. To maintain a steady pressure, the pump must have an air bottle or must be double-acting, i.e., must deliver fluid on both the up and the down strokes of the piston. A pressure gauge is not usually fitted to these pumps, as the pressure can be felt by the operator. The parts of the pump in contact with the fluid should be made of brass. The barrel of the pump is inserted into a bucket or drum containing the dip fluid and is suspended and steadied by the iron foot during pumping. The barrel is about 18 inches (45 centimeters) long and the entry point of the fluid at the base is protected by a coarse, heavy, wire screen. A ball valve prevents back flow. The piston within the barrel needs to be about 1 inch (2.5 centimeters) in diameter and can be sealed by various types of packing, all of which are subject to wear and should therefore be capable of easy replacement. The piston is operated by a handle which should be wide enough to allow its being grasped by both

FIGURE 4. - Bucket Pump Outfit



(1) Two-handed handle
(2) Air vessel
(3) Gland
(4) Leg and foot
(5) Barrel (in which the piston moves)
(6) Foot valve and strainer
(7) Delivery hose
(8) Lance handle
(9) Trigger control valve
(10) Lance
(11) Nozzle

hands. A heavy rubber hose leads from the pump, and a Y junction can be fitted, so that two hoses can be used for spraying an animal on both sides, simultaneously. The hoses should be able to withstand the pressure and should be sun- and chemical-proof.

The hose terminates in a metal lance 18 to 24 inches (45-60 centimeters) long, which should be light, with the center of gravity near the handle. The outlet of the spray is best controlled by a trigger valve, which

should be comfortable and light to operate. The lance terminates in a nozzle head and it is convenient to have this head moveable, so that the spray can be set at different angles from the lance. If this is not available, the head is best set at an angle of 60 degrees from the horizontal, so that the spray can be directed easily at the underparts of the animal. The construction of the nozzle is most important. Swirl plates, having small tangential holes and located deep in the nozzle are not recommended, as the holes are liable to block up and make cleaning difficult. The swirling chamber type with a hand-operated pricker for clearing the jet, as shown in Figure 5, is probably the best. From the nozzle there should come a coarse driving spray, not a fine mist, in the form of a cone or a fan, as shown in Figure 6. Adjustable nozzles should be avoided.

FIGURE 5. - Self-Cleaning Nozzle

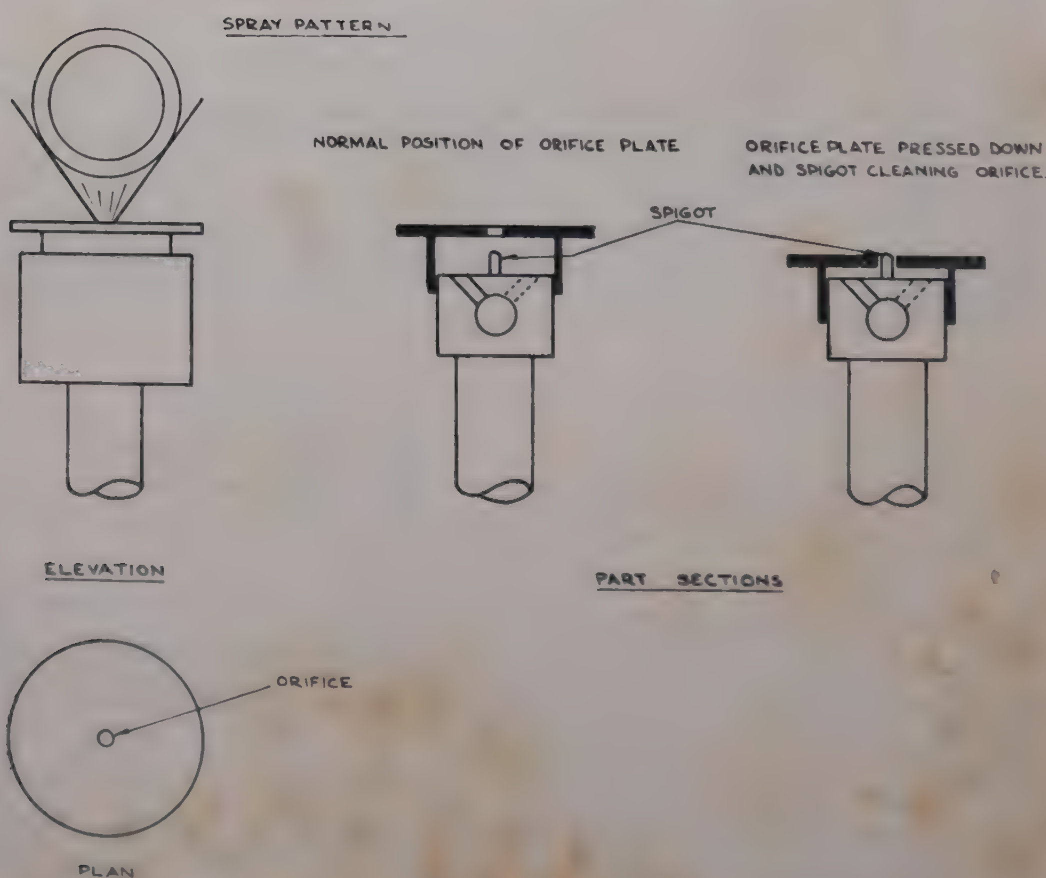
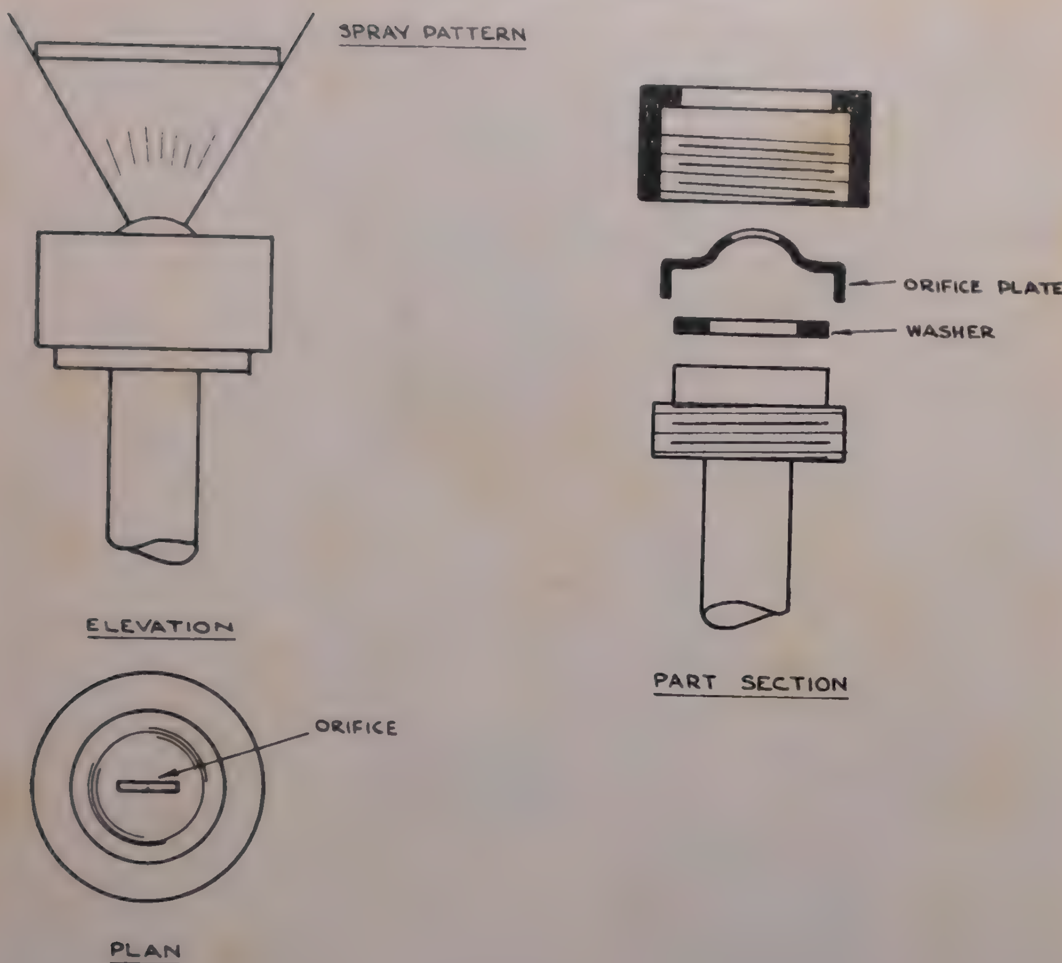


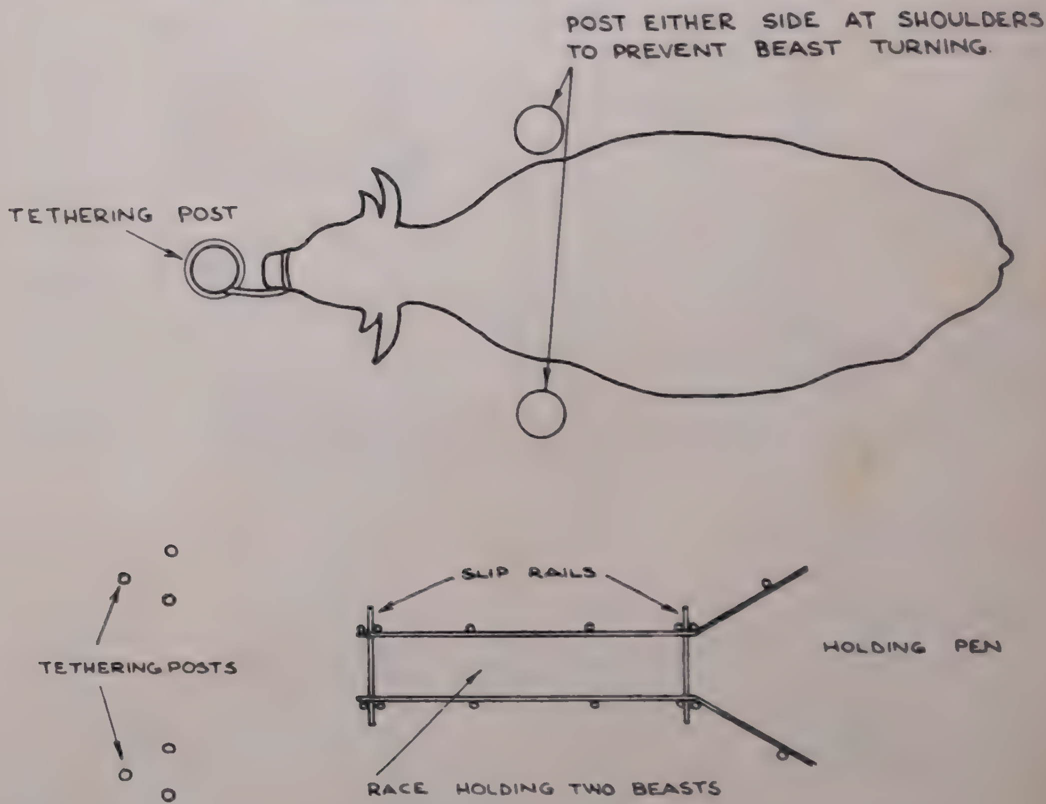
Figure 6. - Fan Spray Nozzle



If the dip fluid, up to amounts of 6 gallons (25 liters) is contained in a bucket or tin, the barrel of the pump can be inserted into it. Larger containers can be used but a suction hose between the pump and the container is necessary. With small containers, the fluid is usually used up quickly and no agitation is required, but with the larger containers the fluid must be kept agitated, especially when the suspension-type dip fluids are used.

Bucket pumps are suitable for spraying from 1 to 50 head of stock and need no permanent installations, except for restraining the animals. No great excess of fluid is applied and recovery of the fluid draining from the animal is not attempted. The simplest equipment of restraint is a post or tree to which the animal's head is tied, with two confining posts level with the shoulders, as shown in Figure 7. These posts are needed to prevent

FIGURE 7. - Method of Tethering Cattle for Hand Spraying



the animal from circling around the headpost. It is best to have a small crush and collecting pen nearby, so that the animals can be roped in the crush and pulled up to the tying post. This does away with the irritation and labor of chasing the wilder animals around the bush.

It is quite easy to spray several animals together in a simple open crush, but if all the parts of the animal are to be properly treated, the animals must be separated by slip rails or, better still, by semisolid divisions, which prevent them from bunching together and hiding under the legs of the beasts in front.

Larger type hand-operated pumps are available for treating more than 50 head of cattle at a time. They are double-acting pumps made of heavy cast iron, and are operated by one or two pumping handles, as shown in Figure 8. A pressure gauge is fitted together with an air vessel of sufficient size to ensure an even air pressure. A suction hose, provided with a foot valve and strainer, conveys the fluid from a container to the pump, and a Y junction enables two delivery hoses to be fitted, each hose

FIGURE 8. - Double-Acting Pump Outfit

(1) Operating handles
(2) Pump body
(3) Suction hose
(4) Foot valve and strainer
(5) Lances
(6) Delivery hoses
(7) Pressure gauge
(8) Air vessel

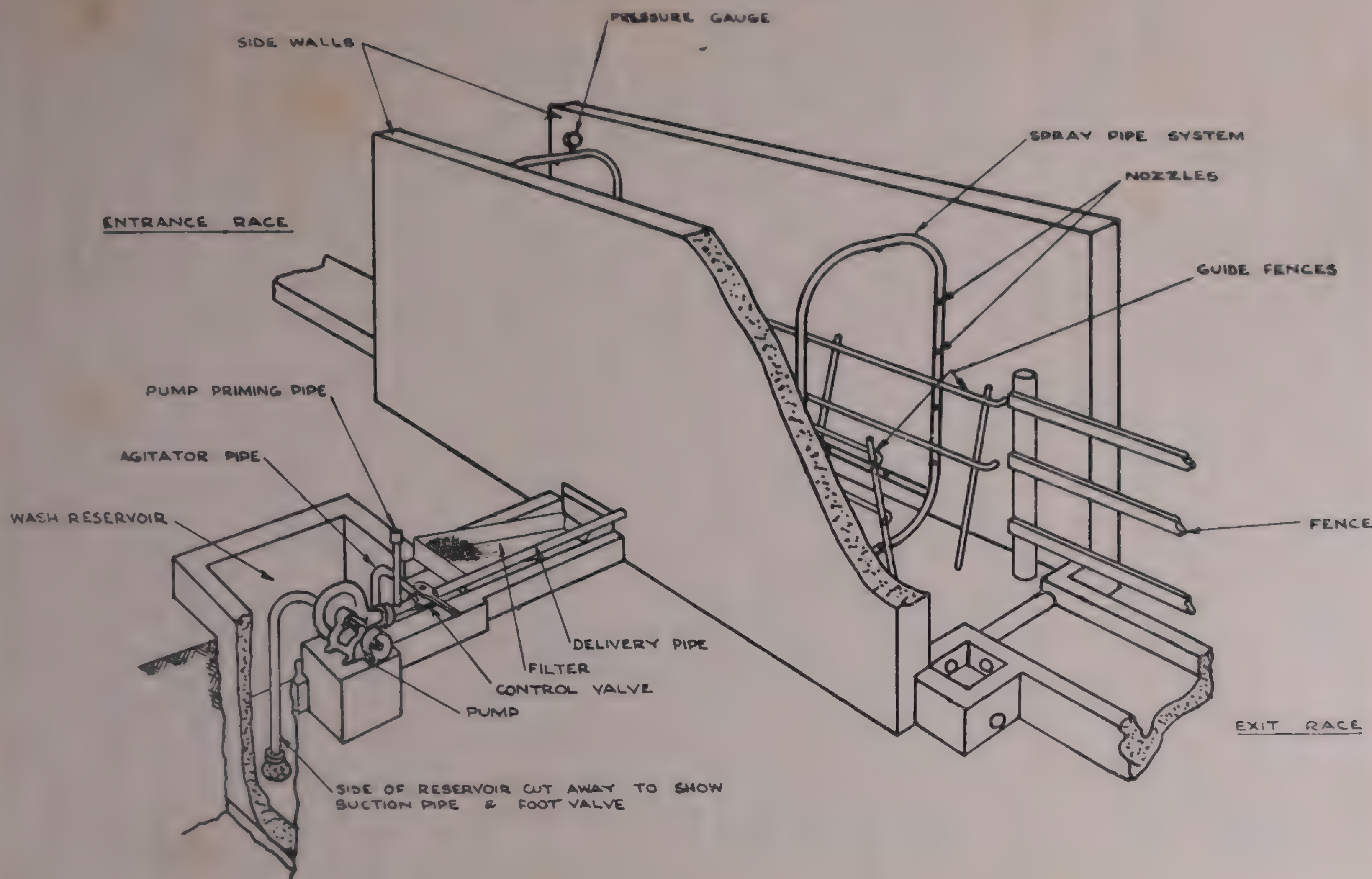
having a spray lance described in the simple bucket pump. Spraying with this type of pump is normally carried out in a crush, and three or four people are required to operate the equipment: one or two for pumping, two for spraying, and several mustering and separating the cattle in the crush. The pump is placed midway along one side of the crush, and one delivery hose passes over a wooden arch to the far side of the crush; each hose must be long enough to reach each end of the crush comfortably. A strict routine of spraying must be followed to avoid some parts of ani-

mals being missed from the spraying. The operators start at opposite ends of the crush and work down toward each other, each man spraying the side of the animal nearer to him, and the head, legs and underparts of the animals in the first half of the crush. It is best to start at the head, directing the first jet into the ear, which is a predilection site for ticks, before the animal becomes aware that spraying is beginning, otherwise it will attempt to evade the spray. The remainder of the head and outside of the ears are important sites for larvae of many species of ticks, which may also be abundantly present under the chin and on the neck, brisket, axillae and groins. The tail must be lifted up and sprayed from tuft to root and brought back over the back to expose the anus and vulva. The feet and heels are sites which are likely to escape attention, especially if they are muddy, and for this reason the floor of the crush should be hard-surfaced, so that the feet do not become buried in the mud and thus inaccessible for spraying. The animals can be well wetted with fluid, using from $^1/_2$ to $^3/_4$ of a gallon (2.5-3.5 liters) for each, and with comparatively little excess dripping off; no attempt is made to recover the drainage fluid. The fairly large-scale application of ixodicides with hand pumps has been described by Clifford (1954) and, in greater detail, by Wilson (1950b).

Power-operated spray races require entrance and exit races as for a plunge dip. They will not be redescribed here but the drainage race is made longer than in a plunge dip, usually 100 feet (30 meters) long. Most of the excess fluid drains off while the animals are walking steadily through the race, and thus a continuous stream of cattle is maintained through the race.

The floor of the spray race is separated from the approach and exit races by a bolster of concrete 3 inches (7.5 centimeters) high. The floor slopes downward from each end to the center, and also from the side opposite to the pump toward the side on which the pump is situated, to allow the spray fluid to return by gravity to the pump. The spray floor is enclosed on each side by a wall 8 feet (250 centimeters) high, which is usually composed of brick or concrete but corrugated iron can also be used. A roof is not essential, but if present, it prevents the loss of a certain amount of fine spray and also tends to prevent animals from plunging when entering the race. Within the walls is placed the framework of piping from which the spray is ejected through special nozzles. There are various types of spray races which differ in length, the disposition of the piping and the number of nozzles. In Figure 9 there is shown a type with only

FIGURE 9. - Cattle Spray Race



an entrance and an exit frame connected by two longitudinal pipes near the floor. Other types may have one or more frames between the two end frames and a longitudinal pipe joining the top of the frames. The piping system has holes at carefully selected points and removable nozzles are fixed over these holes. Their arrangement is such that a complete curtain or wall of spray is formed by the nozzles and all parts of the animal will be wetted, providing the animal is kept in the center of the passage. If the animal passes close to the piping, there are places where the cones of spray do not join up and some parts of the body may escape being wetted. Animals are restrained in the central passage by rails running along the length of the race, inside the spray piping.

The excess spray drains from the floor through a coarse sieve into the wash reservoir or sump. The size of this reservoir depends on the number of animals to be sprayed, but for 400 animals it should hold about 400 gallons (1,800 liters). This allows for the removal of slightly under 300 gallons (1,350 liters) by the animals and leaves sufficient fluid to fill the piping and pumping systems. Larger reservoirs can be built to deal with larger numbers of animals, but as it is recommended that fresh wash should be made up for every 500 head, there is no point in having a reservoir with a capacity of larger than 600 gallons (2,700 liters).

The dip fluid is pumped through the system by a centrifugal pump at a pressure of 15 to 20 pounds per square inch, and a gauge, placed at the highest point of the piping system, must be provided and the pressure correctly maintained. The pump may be operated by a fixed electrical or fuel engine or a mobile source from which the power take-off of a vehicle or tractor can be used. The pump outlet has a valve near the sump: in one position it will return fluid to the sump and it is used to circulate fluid round and round the sump to agitate the ixodicide before spraying starts; in the second position it circulates the fluid through the spraying system; and in the third position both outlets are closed and the valve is used for starting the pump. The return section of the agitator circuit can be made to extend outside the sump and it can then be used to empty the sump.

It is difficult to establish dimensions for spray races but most are between 10 and 18 feet (305 and 550 centimeters) long and have either two or three frames set within this distance. The internal crush rails and the walls extend beyond the piping system, so that the whole race structure will be from 18 to 25 feet (550 to 760 centimeters) long. The material and structure of the nozzles also vary greatly. All nozzles are subject to

wear and blockage but they are replaceable. They should be watched for blockage during spraying and periodically inspected for wear and enlargement of the holes, and replaced with new ones if and when required.

The draining system is the same as in a plunge dip except, as has already been said, the drainage race is longer, because animals pass directly through it without being held. The dip fluid draining from the cattle is returned to the pump through a drainage sump, which is fitted with an alternative outlet to divert the rain water into a drain when the spray is not in use.

When a spray race is first installed, cattle should be trained to it by walking them through the race a few times without spraying being carried out. They may then pass through with the spray operating at low pressure, so that they are not blinded by the fluid and can still see the walls; and finally, they should be introduced to the full-pressure spray. Ordinary water can be used for these trial runs. Cattle will soon pass readily through the race and over 600 head an hour can be treated. In hot conditions, dairy cows can be put through the race in which ordinary water is used to cool them. Cattle of all ages can be sprayed but, as with plunge dips, they should go through according to their age or size groups. In general, emulsion-type fluids are preferred in sprays because there is less adsorption of particles on the long concrete drainage race. Arsenical fluids are not usually used in sprays because of the escape of mist and the danger of building up a deposition of arsenic in the vicinity and also because of the danger to personnel. Excess spray fluid remaining after a day's spraying is discarded.

The spraying of sheep and goats

The application of insecticides to sheep by sprays or jets has long been practiced in the control of "body strike" from dipterous larvae, and particularly when using some of the modern insecticides such as dieldrin, which travels along the wool and has a very long residual effect, these sprays are very effective, and power sprays are employed for the purpose. In general, sprays have not been successful in controlling ticks on the long-wooled breeds of sheep, although some degree of control can be achieved by their use. The haired sheep and goats are more easily wetted and can be successfully treated by sprays for the control of ticks and other ectoparasites. Sheep and goats are not favored hosts for most of the cattle ticks, and *Boophilus* species very rarely infest them, except

B. kohlsi, which is largely specific to sheep (Hoogstraal and Kaiser, 1960). Where herded with cattle, especially in Africa and the Near and Far East, sheep become infested and act as alternative hosts for cattle ticks. They should, therefore, be treated with the cattle in any tick control schemes.

Goats and haired sheep and the underparts of the wooled sheep can readily be treated by the use of hand sprays. This can be done in a crush but a cattle crush is not suitable; and where there are only small numbers, it is better to treat them individually and restrain them manually or by tethering them.

The spraying of equines

Normally, only small numbers of animals are involved, and special spray races would not be built for them. Where a cattle spray race exists, the animals can be trained to pass through the spray and such treatment is effective.

Hand-operated bucket sprays are used for individual animals, and equines which are used for work will soon stand quietly while being sprayed. Equines which are not accustomed to being handled are difficult to treat by any method, but a suitable crush should enable ixodicide to be applied to most of the animals by a hand spray.

The spraying of other livestock

Pigs are not commonly treated for the control of ticks, and insecticides against other parasites are usually applied by swabbing with a cloth or sponge. Insecticides can be applied to them more effectively with hand-operated sprays.

Camels are usually sprayed when treatment for the control of ectoparasites is needed; the large size of the animal makes it preferable to use a double-action hand-operated pump or a power-operated pump.

Turkeys under range conditions have been treated for ectoparasite control by spraying (Gless and Raun, 1958). Poultry kept under range conditions could be more readily treated by spraying than by the more conventional methods of dusting. These authors used a row crop spray boom placed on the ground with the nozzles upward, and the birds were driven through the spray curtain so formed. It enabled 2,600 birds to be treated in an hour, and 1.0 percent malathion and 1.0 percent BHC sprays effectively killed all body lice (*Menacanthus straminicus*).

Hand dressing

There are predilection sites for certain tick species on parts of the body which are not effectively treated by power sprays or dips. The inner parts of the ear are especially liable to escape treatment, and ticks such as *Otobius megnini*, the larval and nymphal stages of *Rhipicephalus evertsi*, and the adult stages of *Rhipicephalus appendiculatus* which feed there, as well as the larval stages of many tick species which are found in the inner fringes of the ear, will not be killed. Other sites escaping contact with the dip are the underpart of the tail, where *R. evertsi* adults are found, the tail brush and the areas between the teats and the legs in cattle with large udders. These sites need special attention and the application of ixodicide selectively to these sites is known as hand dressing. It is normally done as a supplement to ordinary dipping but is sometimes practiced by the owners on individual cattle to control objectionable ticks which occur in small numbers, such as various species of *Amblyomma* and *Hyalomma*. The ixodicide is applied with a cloth, sponge or even a hand spray, and either standard dip fluids are used, or an ixodicide in an oily or greasy medium is employed. Hand dressing of prostrate animals during an outbreak of tick paralysis was useful in reducing losses (Jellison *et al.*, 1951).

The best time to apply hand dressings is in the interval between dippings, but because of the labor of mustering the animals it is usually done at the time of dipping, when the animals are standing in the draining race. There is no objection to this procedure if the standard dip fluid is used, but greasy preparations will not adhere to the partly wet animal. Compounds having a long residual action such as toxaphene are best for this purpose.

Systemic ixodicides

The administration of chemical agents to an animal by mouth, by injection or by other means, so that there is sufficient of the agent in the tissues or body fluids to kill the ectoparasites feeding on the animal, has been the subject of investigation for several years. Systemic ixodicides are likely to be of practical value only if a single administration is effective for a long period; otherwise they have no great virtue over dipping or spraying, since it is no easier to dose or inject an animal than to dip it. The possible advantages would be that treatment could be given to animals

when dipping might be undesirable, e.g., in winter. It would be useful for sheep where the long fleece makes it difficult to have good penetration for tick control. It would also save the cost of providing dipping tanks or sprays. Some success has already been achieved experimentally in this respect by Rafyi and Maghmai (1959), using dieldrin by mouth at the rate of 50 milligrams per kilogram.

The objective of long residual action is not an unreasonable one when consideration is given to the long residual action of some of the trypanocidal drugs, in which a depot of drug maintains a therapeutic level in the blood for some months. The problem of residues in the animals or the animal products, toxic to human beings, is a very real one with the presently available acaricides, and the likelihood of establishing resistance is also an objection.

The general problems associated with the use of systemic insecticides were well reviewed by Radeleff and Woodard (1956), and most of these problems are still present but investigations continue, especially against *Hypoderma* and biting flies.

The initial stimulus to use systemic insecticides came from Lindquist *et al.* (1944), who achieved up to 100 percent mortality in bedbugs fed on rabbits which had been fed on DDT at a dose of 228 to 400 milligrams per kilogram; similar results were obtained by feeding pyrethrins to the rabbits. De Meillon (1946), by feeding gamma BHC to rabbits at approximately 30 milligrams per kilogram, found that the immature stages of bedbugs which fed on the rabbits suffered a 33 to 90 percent mortality; the adult stages were affected but did not die. The rabbit blood became toxic by the second day after the chemical was consumed. Wilson (1948) administered BHC and DDT to calves in attempts to control ticks and tsetse flies on them. Gamma BHC at 65 milligrams per kilogram given on two successive days caused the death of a calf but another calf survived 32.5 milligrams per kilogram on two successive days, and a further amount of 16.25 milligrams per kilogram on the third and fourth days. Several calves were fed multiple doses of 32.5 milligrams per kilogram of gamma BHC at various time intervals, usually 7 or 14 days. The dosed calves were exposed to natural infestation with *R. appendiculatus* in an East Coast Fever-infected paddock. Ticks were affected by the drug, in that very few ticks survived after feeding on the treated calves, but the ticks either fed long enough to transmit the parasite of East Coast Fever, or the few ticks which were not killed transmitted infection, for many of the treated calves subsequently died from the disease, although the incubation

period was prolonged. The lowest dose of gamma BHC which effectively killed the ticks was 16.25 milligrams per kilogram fed twice weekly. Wilson also fed DDT powder containing 83 percent p.p. isomer at 500 milligrams per kilogram to one calf and 250 milligrams per kilogram to another. The drug was not toxic to the animals, but was only moderately toxic to tsetse flies for some hours after they had fed on the treated animals. This supports the results obtained by other workers, who found that parenterally administered DDT was relatively ineffective against biting flies, and of Roulston (1956), who found it ineffective against ticks when fed at a dosage of 25 milligrams per kilogram.

Roulston (1956) tried injecting a number of compounds dissolved in peanut oil subcutaneously into cattle and subsequently exposed them to natural infestation with *B. microplus*. A single injection of lindane, dieldrin and aldrin at 25 milligrams per kilogram produced a marked effect on the ticks. The effect was not immediate but there was a gradual loss of all stages of the tick over a period of 7 to 12 days, and some ticks developed to maturity during this period. The most striking effect was on the larvae from the 7th to the 22nd day, when lindane was used, and from the 16th to the 27th day, when aldrin was injected, and the inoculated animals remained free of ticks during this period. Aldrin and dieldrin continued to affect reinfesting ticks even after they were able to establish themselves as larvae, since the first persistent reinfestation of young adults did not occur until 67 days after the injection of dieldrin and 80 days after the injection of aldrin. There is some evidence that 25 milligrams per kilogram is close to the lowest effective dose in the case of dieldrin and aldrin. This minimal effective dose may not apply to all species of ticks, as MacGregor and Bushland (1956) say that during experiments against *Hypoderma* and *Callitroga* spp., cattle treated with lindane and aldrin at 50 milligrams per kilogram and dieldrin at 25 milligrams per kilogram were grazed in pastures heavily infested with *Amblyomma americanum* and there was no noticeable effect on the ticks on them.

It seems probable that repeated injections of doses of lindane, aldin or dieldrin at 25 milligrams per kilogram can be given to control ticks, as MacGregor *et al.* (1955) injected cattle subcutaneously with 25 milligrams per kilogram of dieldrin and 50 milligrams per kilogram of lindane six times at 28-day intervals without injury; one animal out of four, however, died after a third injection of 50 milligrams per kilogram of aldrin. More extended trials of the toxicity of single and repeated doses will have to be made, since Lindquist *et al.* (1953) reported the death

of three calves after the subcutaneous injection of 10, 25 and 50 milligrams per kilogram of lindane respectively, although other calves in these groups survived these dosages.

Roulston (1956) found the following compounds were ineffective against ticks when injected subcutaneously into cattle at 25 milligrams per kilogram: diazinon, malathion, DDT and toxaphene. Neguvon given by mouth at 50 milligrams per kilogram produced no effect on ticks when used by Roulston against *B. microplus* but Adkins and Arant (1957) found this compound effective against the nymphal stage of *A. americanum* when fed on rabbits which had been dosed by mouth. At 50 milligrams per kilogram the drug killed 88 percent of the nymphae, and at 100 milligrams per kilogram a 100-percent kill of ticks was recorded.

Menon *et al.* (1954) dosed fowls with toxaphene at 250 to 500 milligrams per kilogram by mouth and caused a 73 to 100 percent mortality in *Argas persicus* feeding on them during the week following dosing. The fact that *Boophilus* failed to respond to this drug in Roulston's experiment may be due to the great difference in dosage levels employed, rather than to a different response of the tick species.

From all the foregoing experiments it is evident that the systemic use of ixodicides offers some promise but there are some inconsistencies which need clarification, and it appears that the route of administration, the species of tick, and even the host species may affect the result.

The expense of using the chemicals dissolved in bland oils such as peanut oil was considerable because of the large quantities needed, and it would seem worth while to test the effect of the same compounds as undissolved suspensions in a similar way as the protective trypanocidal drugs.

IV. TIMING OF IXODICIDAL APPLICATIONS

There are two aspects to the timing of the application of ixodicides which, for convenience, will be referred to as "dipping," although of course it applies to any method. The first is the dipping interval, or the number of days which elapse between each dipping, and the second is the seasonal intensity of dipping or strategic dipping.

The dipping interval depends on the tick species to be controlled and is determined by the length of time that any of the instars takes to feed. If there is a continuous breeding cycle throughout the year, there will be larvae, nymphae and adults present at all times, and in order to deal with all stages with at least one application of ixodicide, the interval must be as short as the shortest feeding time of any of the instars. Thus, for *R. appendiculatus*, a three-host tick, the larval stage is on the host from three to six days before dropping engorged, the nymphal stage five to eight days, and the adult some days longer. Assuming that the dip kills all the ticks at each application, then on the first dipping day (D.D. 1) all ticks will be killed. On D.D.1+1 day fresh ticks will be picked up, and of these, larvae will begin dropping by D.D. 1+4 days. To ensure that all larvae are killed, they must be attacked before the oldest of them have dropped, and the second dipping (D.D. 2) must take place on D.D. 1+3 days. To ensure that all nymphae are killed, D.D.2 must be D.D.1+5 and, for the adults, D.D.1+7. It is obvious that if the regular dipping interval is D.D. 1+7, all adults will be killed but a small proportion of nymphae will survive, and quite a large number of larvae will escape, since there will be ample time for larvae to attach, feed, and drop off between D.D. 1 and D.D. 1+7. Thus, in many parts of Africa, where some larvae, nymphae and adults are present throughout the year, although there may be seasons when some stages are less frequent than others, a dipping program for complete tick control might require immersion every fourth day. With a one-host tick such as *Boophilus*, where the larval,

nymphal and adult stages are all spent on the same animal, each tick is present on the animal for 18 to 29 days. Thus, if all the ticks are killed on D.D. 1 and fresh ticks are picked up on D.D. 1+1, dipping again on D.D. 1+18 would kill all the ticks, and on D.D. 1+21 days would kill most of them. Hence, a dipping interval of three weeks is theoretically adequate for control of this species although, as will be seen later, there are factors which slightly modify this.

The dipping interval to be observed is complicated by the objective desired from the dipping. If the only objective were the reduction or elimination of ticks, it would probably be sufficient to concentrate either on the most vulnerable stage or on the reproductive stage. The most vulnerable stage is the larva, which would mean short-interval dipping, since this is the stage of most rapid feeding. Because it is the most vulnerable stage, a lower concentration of ixodicide can be used and, indeed, with the more toxic ixodicides it must be used. Thus, for the control of larvae, short-interval dipping in weak ixodicide would be adopted. It is more logical to attack a parasite at its reproductive stage, since any engorged female which drops may mean a thousand or more larvae to be combatted later. The adult stage, particularly the engorging female, is one of the most resistant stages and therefore a high concentration of ixodicide must be used to control it. Many ixodicides, although they do not kill the females, prevent them from laying viable eggs, and thus 100 percent control can be achieved, although the kill may be only 80 percent. The interval between dippings may be increased, however, because the adult stays on the animal longer than the larva. Thus, to control the adult stage one would use a high concentration of the ixodicide and, in order to avoid toxicity, also the longest possible interval between dippings. In practice, it has been found that if regular dipping takes place throughout the year, an interval of D.D. 1+6 days (seven-day dipping), in a strength of ixodicide which will kill adults, provides a satisfactory control of three-host tick species, since this strength will kill all stages and the larvae and nymphae which escape contact with the ixodicide will be killed at a later stage. Where tick reduction rather than tick eradication is aimed at, for reasons of preserving immunity to tick-borne disease in the stock, a longer dipping interval, usually of two weeks, is practiced.

An additional factor in deciding the dipping interval is the need to prevent disease transmission. In the prevention of East Coast Fever, which is transmitted by *R. appendiculatus*, it is known that only stage-to-stage transmission occurs and that the infection does not pass through the tick

egg, so that only the nymph and the adult can transmit the infection. A long-term policy of tick eradication would, of course, ultimately result in disease eradication but the immediate problem of preventing disease while ticks are still present must continue to be faced in most parts of East Africa. This means that the ticks must be killed before they have time to transmit infection to the animal. It was thought formerly that the ticks had to feed for three days before they were able to transmit infection and, therefore, to control an outbreak of disease, three-day dipping was practiced. This was not very successful, partly because arsenical dips were largely used, and the concentration of arsenic had to be so low for that frequency of dipping that many, especially the adults, were not killed, and partly because it has since been shown (Barnett, 1959; unpublished) that infection may be transmitted by some ticks as early as 24 hours after attachment. If absolute control of *R. appendiculatus* were desired from the point of view of disease transmission, it would theoretically be necessary to dip animals every 24 hours in an ixodicide such as arsenic, which has no residual action. This is clearly impossible, but the situation has been changed by the use of ixodicides which have a long residual action. It must not be thought that this problem is constantly before the stockowner in East Africa, for such is not the case. The usual practice is to reduce tick infestation in a fenced area by introducing immune stock and dipping them regularly for at least a year, so that there is very little risk of infected ticks being present; but infection may be introduced or new land may be used for grazing, and under such circumstances, dipping in 0.5 percent toxaphene, which has a residual effect of five to seven days, will normally prevent infection if the interval of dipping is five days, and in areas of low infection rate in the ticks even seven-day dipping will be effective. In areas of heavy infection even three-day dipping in toxaphene may not protect all animals. If an ixodicide with little or no residual effect is used, such as arsenic, an interval of five days or better, five, four, five days in seven-day strength (0.16 percent) is better than three-day dipping in three-day strength (0.08 percent).

The same considerations would apply to *Boophilus*, if the primary reason for tick control were to prevent infection with *Babesia*. At present, it is not agreed which stage of *Boophilus* transmits the infection, but if it is the larval stage, then three-day dipping might have to be used; if it is the nymphal or adult stage, then a much longer interval would be sufficient, viz., 6 days for nymphae and 12 days for adults.

The complicating factor concerning the control of *Boophilus*, which was mentioned earlier in this chapter, is the resistance of the premoulting stages of larvae and nymphae which are protected by an extra sheath of chitin and tend to escape the effect of the ixodicide. This, together with the fact that few, if any, of the ixodicides are 100 percent lethal to all stages of the tick, especially the adult stage, means that quite large numbers of *Boophilus* will escape the effect of dipping, if the interval is at the maximum time of 21 days. A really effective attack on this species ought to ensure that three applications of ixodicide are made within 21 days, so that the stages missed at one application will be dealt with by the second, and the immersion interval should therefore be seven days, although considerable reduction in tick numbers can be effected by dipping at 10 to 14-day intervals.

The dipping interval is also influenced by economics and human interest. Dipping means financial expense for the ixodicide used, and for the time and labor spent in mustering and immersing the animals; there is also some loss of production. These factors must be balanced against the economic loss caused by the ticks. One or two milking cows dying from tick-borne disease may cost more than dipping the herd every five days for a year and, therefore, despite the inconvenience to the farmer, he would dip every five days in order to prevent that loss. On the other hand, even ten-day dipping intervals might be considered unreasonable or uneconomic in parts of Australia, where mustering can be difficult and some degree of tick infestation is desired to perpetuate immunity to *Babesia* infection.

In conclusion, it can be said that a dipping interval can be calculated from the known life cycle of the tick and from the properties of the ixodicide employed. This theoretical dipping interval may have to be modified by practical experience, and finally, as with most human activities, there is a compromise between what is most desirable and what is most convenient. It is, for instance, easy to get into the routine of dipping every seven days because, having chosen a convenient day, dipping will be carried out on that day throughout the year, but if a five-day interval is used, dipping will fall on a different day each time and often on inconvenient days like Sundays, when labor resents it, and the rhythm of the farm work is upset by dipping on varying days.

The second aspect of the dipping interval, namely the intensity of seasonal dipping or strategic dipping, has been receiving attention in recent

years. The seasonal incidence of ticks or of certain stages of the tick is well marked with some species and has been referred to earlier in this publication. The spring rise in numbers of *Ixodes* in Great Britain and a lesser rise in the autumn, with relative freedom from ticks in the summer and winter, meant that ixodicidal treatment for the prevention of tick worry needed to be carried out only during the spring and autumn, or even only in the spring. Similar seasonal incidence of other species, such as *Hyalomma* in North Africa, would limit the need for dipping to between late spring and late summer.

Dipping at a time when the tick is most numerous does not necessarily mean that this is the most effective time at which to control the species. It might well be that the species would be most vulnerable at a season when it was least numerous. For instance, a species which overwinters in the engorged nymphal state might be more effectively controlled by intensive dipping in the autumn, when it is comparatively rare on the animals, than in the spring or summer, when other stages are numerous. This aspect of strategic attack has not been given sufficient attention but it has been used in Australia in the control of *B. microplus*. In the Brisbane area, the tick population is markedly reduced in the winter and early spring due to adverse conditions for reproduction in the late autumn and early winter, although there is a small turnover of ticks during this adverse season. The progeny of ticks, which are dropped from late July to early September, tend to hatch at about the same time in September or October, producing the spring rise of larvae. These larvae result in a mid-spring generation of adults, which may become the parents of a heavy early summer infestation of ticks in November, December and January. This generation may give rise to an even heavier infestation in late summer and autumn. Intensive dipping of a trial herd of cattle in spring (September and October), attacking the first larval infestation, so reduced the reproductive potential, that dipping of this herd could be relaxed to intervals of 49 to 70 days in the summer, at a time when gross infestation of the neighboring herds made it very difficult to control tick numbers when they were being dipped at 28-day intervals. It should be pointed out that in this experiment, described in more detail by Norris (1957), tick eradication was not desired but only limitation of the ticks to reasonable numbers.

A somewhat similar seasonal incidence of various tick species occurs in South Africa, although the season of low incidence is shorter. This

incidence is diagramatically illustrated in an article by Purchase (1955). Wilson (1946 and 1950 a) describes a definite seasonal incidence in the numbers of certain instars and species of ticks in Nyasaland. The seasonal increase in numbers of ticks in South Africa in the warm, humid months is recognized as a time when the normal routine of dipping may have to be intensified in order to maintain effective control of the ticks.

The practical utilization of knowledge on the seasonal cycles of ticks is beginning to be applied in various parts of the world, but it is evident that much experimental work in this field still remains to be done.

V. IXODICIDES

Arsenic

Arsenic was the first ixodicide to be widely used, and it is still one of the cheapest and most effective agents for the control of cattle ticks. It is used in the form of sodium arsenite, which is soluble in water. Wetting agents and cresols are added to the commercial preparations of arsenical dips. Arsenical solutions can be prepared on the farm from commercial sodium arsenite, soft soap and kerosene, but care must be taken that the arsenic content is known, as commercial samples vary in their content of sodium arsenite. Arsenic preparations should be made only under expert supervision.

The strength of arsenic employed depends on the frequency of dipping but the maximum strength is limited by its toxicity to the animal and should not exceed 0.24 percent. Strengths of arsenical dip solutions are always given as a percentage, being the weight of arsenic calculated as As_2O_3 in 100 volumes of water. The minimum effective strength against most species of ticks is 0.16 percent, and this strength is employed where the dipping interval is seven days, although slightly lower strengths can be effective where precise concentrations of wetting agents are employed. A weaker strength of 0.08 percent was formerly recommended for dipping at three-day intervals but the percentage kill of ticks at this strength is too low to counterbalance the good results achieved by frequent application, and five-day dipping in seven-day strength is a better procedure.

In countries where *Boophilus* ticks are the sole or principal ticks and the dipping interval is ten days or longer, strengths of 0.2 percent to 0.24 percent are used. Countries which have made regulations for the control of *Boophilus* have laid down minimum legal standards of 0.20 to 0.22 percent. In the United States the official dip strength is 0.22 percent; in Australia, Jamaica and parts of South America it is 0.20 percent.

The chief advantage of sodium arsenite is its solubility in water, and problems of selective adsorption, settling out, or cracking of emulsions do not arise. It is stable in dip tanks, although oxidation changes discussed in Chapter VI can occur. It is effective against all species of ticks, although some are less responsive than others, and it affects all stages of the tick. It is probably more effective against the adult stages than are most of the ixodicides. The strength of the solution is easily and accurately determined, and with a vat-side testing outfit a dip manager can carry out frequent analyses and immediately adjust any variation from the proper strength. The disadvantage of arsenic is its toxicity. The occurrence of tick resistance to arsenic is not a special disadvantage, as it is a problem inherent in all ixodicides.

Arsenic has very little residual effect against cattle ticks. The period of protection against *Boophilus* is given by Legg and Foran (1929) as one day and by Craybill (1913) as two days. Observations on larval infestations with *B. microplus* in Australia (CSIRO, 1934) showed that cattle became reinfested within 36 hours and that such ticks could reach maturity and lay eggs. African experience of arsenic against three-host tick species suggests that it is not longer than one day. Milne (1945 a) says that the residual effect of an arsenic-derris dip on sheep is longer than this, that the sheep remained free from *Ixodes ricinus* for seven to ten days, and that reinfestation was not complete until three or four weeks after the last dipping. This residual effect may have been due to the derris constituent, but MacLeod (1947) records a residual effect of arsenic in sheep and says that the duration of this residual effect is enhanced by the addition of wool fats in the dip.

The mode of action of arsenical dips appears to be more than that resulting from the direct application of the chemical to the tick itself. Considerable quantities of arsenic are present in the skin and hair of cattle subjected to regular dipping, and this deposition is said to explain the fact that when cattle are first dipped in arsenical baths, the tick control is not as good as in later weeks, after the cattle have been dipped several times. On the other hand, the arsenic content of the skin and hair persists for long periods, and since the residual effect is so short, this local deposition of arsenic is evidently not sufficient to be lethal to the tick by contact or ingestion.

The maintenance of arsenical dip baths is relatively easy, since dipped animals remove only the standard solution and the fluid which drains back into the dip is still of the standard strength. Replacement

of the removed fluid is done by adding the necessary quantity of dip of the standard strength. The problem of selective adsorption which arises with the suspension and emulsion dips, discussed in Chapter VI, does not arise with arsenical dips. Adjustments to the strength have to be made from time to time because of evaporation or flooding or for other reasons, and monthly testing of the dip strength is desirable, although three-monthly testing is more usual. Newly charged dips may show unaccountable variations in strength for several weeks.

Great care must be observed in the disposal of dip fluid and utensils and containers which have held dip. Cattle will readily seek out dried arsenical residues and eat lethal quantities. For the same reason, sensible procedures in dipping the animals are most essential when an arsenical dip wash is used. Cattle should not be dipped until they are rested and have been allowed to drink. They should be dipped in the cool, dry time of day, to avoid skin damage and absorption of arsenic from the skin. The dip and dip environs should be well fenced, to prevent the access of stock at times other than dipping.

Nicotine

Nicotine is prepared from waste tobacco leaves. It is available either as crude nicotine, containing 95 to 98 percent alkaloids, or as nicotine sulphate containing 40 percent alkaloids. It is readily soluble in water, and nicotine alkaloid is volatile.

Nicotine was employed in Australia and South Africa together with arsenic to combat arsenic-resistant *Boophilus*, but as soon as the effectiveness of the chlorinated hydrocarbons was established its use was discontinued. It is an effective ixodicide in fairly high concentrations but at those concentrations it is expensive. In South Africa its use in dipping vats is permitted at a strength of 0.05 percent with replenishment at 0.075 percent, provided sodium arsenite is also present at a concentration of 0.16 to 0.20 percent. It has been employed in oils and greases for the hand dressing of predilection sites but it has no virtues over the modern insecticides for this purpose. It has been used to paint perches in fowl houses for the control of mites and ticks. Being volatile, it may exert some effect on the parasites of the birds as well as those on the woodwork of the henhouses.

Derris

Derris has proved a useful ixodicide for the control of ticks on sheep and small animals. It is used as the powdered root or as an emulsion of an extract containing 25 to 45 percent of the active principle, rotenone. It is not of practical value in the control of cattle ticks, but it was used for many years against sheep ticks in the United Kingdom.

MacLeod (1947), using *in vitro* tests with rotenone emulsions on *Ixodes ricinus*, obtained 100 percent kill with one part of a 10 percent derris extract (27 percent rotenone) in 100,000 parts of water, but lower dilutions took several days to kill the ticks. In field trials, the extract killed all ticks in dilutions as low as one part in 15,000.

Derris powder, diluted with inert fillers, such as Fuller's earth, was tried in sheep against *I. ricinus* by Milne (1945 a). He noted, with both powder and emulsions, that many ticks were killed before they attached, that after the powder was used, the number of unattached females was greatly increased, and that these all ultimately died. A grave disadvantage of the powder was the irritation caused to the sheeps' eyes, many animals becoming totally blind. With care, lambs could be treated, especially on their undersurfaces, without the development of keratitis.

Derris preparations were at one time commonly used in treating ectoparasites on dogs and cats; they were used either as powdered ground root diluted with filler, as water suspensions of the powder, or as emulsions of the extract. Smith, Cole and Gouck (1946) describe the control of the dog tick, *D. variabilis*, on dogs in America with derris as a suspension of 1 ounce of derris powder and 1 ounce of neutral soap in 1 gallon of water.

There is some residual action in sheep, according to MacLeod (1947), who gives the maximum effective duration of a single treatment as 14 to 17 days. The residual effect on dogs is much less: Clunies-Ross (1935) found that a suspension of powdered root in water protected dogs against *Ixodes holocyclus* for only three days, and Smith, Cole and Gouck (1946) found that twice-weekly treatment of dogs was needed to protect them from *D. variabilis*.

Pyrethrum

Attempts are being made to use pyrethrins to control ticks that have become resistant to other insecticides. Natural pyrethrins are available as 25 percent extracts, in which form they are stable. The active principle

is insoluble in water and is used as an ixodicide in an emulsion. In this form, and especially in a thin surface film, it is unstable and quickly oxidized to inactive compounds. Stabilizers are being developed which may improve the keeping quality, but at the moment pyrethrum ixodicides are only suitable for use in sprays. Pyrethrins kill all stages of ticks rapidly but they have no residual effect.

Field trials in East Africa suggest that the effective killing strength is from 1/1,000 to 1/2,000 of the extract (E.A. Farmer and Planter, 1958). In *in vitro* trials on strains of *Boophilus* resistant to various groups of ixodicides, Whitehead (1956) showed that larvae from a strain resistant to arsenic, BHC and DDT were 18 times more tolerant to pyrethrum than larvae from a strain susceptible to all ixodicides. Tolerance of this order is greater than would be expected from vigor tolerance and, as pyrethrum has never been used against ticks in South Africa, it cannot be an acquired tolerance. Whitehead found that the adult *Boophilus* was incredibly sensitive to pyrethrum. Using a 10 percent emulsion of the 25 percent extract at progressive dilutions, he obtained a 96 percent mortality *in vitro* with a 0.1 percent times 10 to the minus 6 dilution.

The cost of pyrethrum makes it probable that it can be employed only for specialized conditions, such as the prevention of spread of resistant ticks. If pyrethrum could cause rapid and certain kill of ticks resistant to normal ixodicides on cattle to be moved to a clean area from an area where resistance occurs, the cost of a single application would be well spent, but the existence of resistant diptera and the increased resistance of the ticks in Whitehead's trials suggest that tick resistance to pyrethrins would eventually develop.

The chlorinated hydrocarbons

DDT (p′p′ - dichlorodiphenyl trichloroethane)

The para para isomer is the active biological form and constitutes about 70 to 80 percent of the total chemical agent in commercial DDT. Several related compounds such as methoxychlor exist but there is little information about their activity as ixodicides. DDT is chemically stable in dip tanks but some formulations undergo physical changes in dip washes. It may be employed as a suspension or as an emulsion.

In Australia the formulation used is referred to as a colloid and is prepared by heating the concentrate and pouring it into the dipping tank, where it separates out in fine colloidal particles. It seems agreed, however,

that the fine particles become aggregated into particles of other suspended matter and, in effect, become a suspension, but Roulston *et al.* (1958) have demonstrated a difference in the behavior of colloid and suspension-type dips on ticks even after repeated use. Some stripping out of the compound then occurs, for Norris (1956) records a greater deposit of DDT on cattle passing through a dip which has been used several times than on cattle which pass through a newly charged dip. With the colloidal type of dip preparation, the stripping action is sufficient to afford the cattle extra protection but not sufficient to cause difficulties of excessive depletion. It should be noted that the strength of DDT used in Australia is higher than in most parts of the world and some loss by extra adsorption can be allowed. It has been calculated (CSIRO, 1954) that more than 1,000 micrograms of DDT per gram of hair are needed to protect animals against reinfestation with *Boophilus* larvae.

Particulate suspensions of DDT are available either as wettable powders or as pastes, both of which contain wetting and dispersing agents. Emulsions of DDT are commonly used and are satisfactory in dips. DDT is employed as an ixodicide because of its ability to control *Boophilus* ticks which have become resistant to arsenic. It is not effective in controlling other species of ticks, and indeed its lethal effect on *Boophilus* is not particularly good in respect of its percentage kill of all stages. Nevertheless, it is very effective in controlling *Boophilus* on cattle, and this is due to the high killing rate of the larval stages together with a residual effect for several days. Its lethal effect is mainly on the larvae, unless high concentrations like 0.5 percent are used, and many people are disappointed when they first use DDT, because adult forms are still frequent after the first two dippings at weekly intervals, and it is not until the third week, when all fresh larval infestation has been killed and all the immature stages on the animal have completed their cycle, that its effect becomes evident.

The strength of DDT employed varies in different countries, and this may in part be concerned with the cost of use of the product. In South Africa, Bekker *et al.* (1949) calculated that the cost of filling a dip with 0.1 percent DDT and replenishing it at the rate of 0.2 percent was 10 shillings per animal per year. At this strength it gave excellent control of *Boophilus* but practically no control of the three-host tick species, so that it was necessary to add further constituents to the dip; if arsenic was used it would add a further 1 shilling and 3 pence to 3 shillings and 4 pence per year per head, depending on which arsenical preparation was

used. To use DDT at the strength of 0.5 percent as in Australia would have cost 29 shillings per head per year, which was regarded as uneconomic. However, it is likely that the new regulations governing the use of DDT in South Africa will require that dips shall be charged at the rate of 0.3 percent and replenished at the rate of 0.45 percent.

In countries where DDT is used to control *Boophilus* but where other species of ticks also occur, it is necessary to add other ixodicidal agents to the tank at the concentrations at which they would be effective if used alone, i.e., arsenic at 0.16 percent or BHC at 200 to 300 p.p.m. The United States Agricultural Research Service (1954) recommends that DDT as a wettable powder be used at a strength of 0.5 percent for control of lice and horn flies but that for tick control, enough BHC wettable powder be added to give 250 to 300 p.p.m. of the gamma isomer.

In South Africa Bekker *et al.* (1949) found that a 1.2 percent DDT suspension dip was quite unsatisfactory but that a 1.0 percent emulsion was effective, although the strength was found later to be suboptimal and replenishments had to be made at 0.2 percent. These authors found that the addition of arsenic prevented the emulsion from breaking up, which occurred in the absence of arsenic, slowly forming a suspension which lost its strength much more rapidly. Their observation of the stabilizing effect of arsenic on the DDT emulsion was confirmed by Blomefield (1952). In Australia, on the other hand, the combination of arsenic and DDT is not recommended (Queensland Agricultural Journal, 1954), presumably because of the finding by Maunder (1956) that DDT delays the excretion rate of arsenic and predisposes to arsenical poisoning. Blomefield (1952) records field trials with DDT emulsions at a strength of 0.225 percent and also in sprays at 0.15 percent, 0.225 percent, and 0.3 percent respectively. Complete control of *Boophilus*, which was resistant to BHC, was obtained at all strengths except in the dip, where owing to sedimentation and inadequate agitation due to the small numbers of cattle dipped, the strength fell to below 0.15 percent. Even at 0.3 percent the DDT did not control the two- and three-host ticks. A DDT wettable powder dip at 0.5 percent gave good control of *Boophilus* but incomplete control of the two- and three-host ticks. Treatment in all cases was at weekly intervals.

In South America DDT has been used extensively where arsenic-resistant *Boophilus* occurred. It was used at 0.2 percent initially but more recent reports advise 0.25 to 0.4 percent.

It is concluded that, as with BHC, the initial strengths of DDT em-

ployed were the minimal effective strengths and that with continued experience, strengths have been progressively increased. The recommended levels now are from 0.25 percent for short-interval dipping (7 to 12 days) to 0.5 percent for long-interval dipping (14 days or more). At strengths of 0.4 percent or more, it is not necessary to use a higher concentration for replenishing the dip fluid, but when the dip strength is 0.25 percent or less, replenishment should be at 0.3 percent or over, in order to replace the chemical stripped out by the stock.

The contradictory evidence concerning the type of formulation used, i.e., emulsion or suspension, seems to depend on the quality of the particular product used. With carefully formulated dip fluids, emulsions and suspensions can be equally satisfactory. Australian experience shows that their colloidal suspension remains effective for some years in a dip, even when the fluid is heavily fouled.

Benzene hexachloride (BHC; HCH; 1, 2, 3, 4, 5, 6 Hexachlorocyclohexane. Lindane and gammexane refer specifically to the gamma isomer)

There are at least 5 isomers of this chemical, of which the gamma isomer is the active biological constituent. Crude BHC contains about 13 percent of gamma isomer and lindane consists of 99 percent gamma isomer. Where strengths of BHC are referred to in discussions on ixodicidal action, the percentage concentration of gamma isomer must always be used. BHC is virtually insoluble in water, and is, therefore, applied as a powder or suspension, or is dissolved in an organic solvent and applied as an emulsion in water.

BHC became available in the early 1940s at a most opportune time, when the resistance of *Boophilus* to arsenic was causing great concern in many countries. It is an extremely efficient and cheap ixodicide but, as with DDT, records of the early use of the compound give a confusing picture, because the strengths used were suboptimal and the behavior of the various formulations in dips and sprays was not properly understood. Bekker *et al.* (1949) record extensive field trials with BHC which took place over a number of years in South Africa. The effectiveness of BHC was compared with that of DDT and of arsenic against various species of ticks. Emulsions were considered unsatisfactory because of the exhaustion effect and some instability. This was so great in sheep dips that it was found impracticable to use them for sheep. In cattle dips, emulsion dips gave a good kill of ticks but even at the highest concentration used,

when the tanks were filled at 100 p.p.m. and replenished at 200 p.p.m., the usual strength of the dip was maintained only at about 80 p.p.m. A similar result was found with suspension dips, where charging the tanks at 100 p.p.m. and replenishing at 200 p.p.m. resulted in strengths of 75 to 90 p.p.m. From a survey of 100 dipping tanks of farms which used BHC, where the strength should have been 100 p.p.m., 84 percent were below 50 p.p.m. and 35 percent were below 20 p.p.m., and it was concluded that it was impossible for the farmer or the dip inspector to maintain the correct concentration. Similar difficulties in maintaining correct concentrations had been encountered in other parts of the world, but the effectiveness of the chemical was generally accepted and BHC was being extensively used in dips and sprays against all species of ticks on both cattle and sheep. Blomefield (1952) concluded that a 200 p.p.m. suspension of BHC was superior to 0.16 percent arsenic against three-host ticks in South Africa, and although loss of efficiency occurred, this strength was effective in dips for up to 12 months. If it was not used in combination with DDT or arsenic, he recommended that it should be used at 300 p.p.m.

In Australia BHC was extensively used against *Boophilus* at concentrations of from 150 to 650 p.p.m., with good results even at the lower levels, and its rapid effect on all stages of the tick was noted. Mention is made of a tank (Yeerongpilly, Queensland, 1954) which had been charged for six years and which still gave good control, using 300 p.p.m., although the phenomenon of loss of efficiency of the gamma isomer had been recognized in Australia some years earlier (CSIRO, 1953a and Roulston and Hitchcock, 1953).

Resistance of *Boophilus* had been found in the late 1940s but BHC was still being employed in many parts of the world, sometimes at strengths much below those recognized as satisfactory today. Brander (1956) noted that in Jamaica dip strengths had been 125 p.p.m. in 1948 but that it was being used at 250 p.p.m. in 1956. Yeoman (1956) records the effective control of three-host ticks on a large scale in dipping tanks in Tanganyika over many years, using BHC suspensions in the tanks at 100 p.p.m. The probable reason for the success of these tanks was that they were communal tanks, used constantly every day and replenished with fresh BHC after every few hundred head had passed through them, so that settling, depletion and deterioration had no chance to affect them.

The strengths recommended today vary from country to country and depend to some extent on the species of tick being controlled and on the existence of resistance to the chlorinated hydrocarbons. The mini-

mum amount is 300 p.p.m., except for short-interval dipping every three to seven days, when 250 p.p.m. is adequate. The maximum amount used is 500 p.p.m. The present trend in formulation favors emulsions but there seems to be little real evidence to support this preference. The dispersible powders have advantages for the small stockowner who uses hand sprays, in that they are more readily stored and measured out in small amounts; and when applied by hand sprays and the return wash is not re-used, the question of selective removal and deterioration does not arise. The wash in the containers needs continued stirring to prevent sedimentation during application. Where communications are poor (and transportation difficult) a small bulk high BHC-content product is needed and the dispersible powders offer some advantages over emulsions.

Special formulations for particular purposes are employed. Dusts are especially useful against ectoparasites of poultry, as has been described in Chapter III but, in general, they are not very efficient on mammals, although their use has been recommended (Gregson, 1951). The use of BHC in emulsions or greases for hand dressing animals has proved very effective, although toxaphene, by virtue of its longer residual effect, is probably better for this purpose. Brander *et al.* (1953) found that the application of a creamy salve containing 300 p.p.m. was the best way of controlling *Ixodes* infestations on new-born lambs. This salve could be easily carried by the shepherd and applied to the lambs without upsetting the ewes or the lambs, and it was not unpleasant for the shepherd to handle.

The residual effect of BHC does not appear to be influenced greatly by the formulation employed, but like most ixodicides, it is influenced by the concentration of the dip. Even at the highest concentrations, the residual effect to give complete protection against larval reinfestation is not more than two days, but there is some degree of control for up to five days in cattle. The residual effect on sheep against *Ixodes ricinus* lasts for some three weeks. Residual effects as long as ten days have been recorded (Pokidov, 1957) but this is not the general experience, especially against the three-host ticks.

Toxicity, following the use of BHC, is not commonly reported and when it has occurred, it has usually been due to the breaking of an emulsion in the dip and the consequent heavy deposition of high concentrations of solvent containing BHC on the animals. The toxic effects are the same as for the other chlorinated hydrocarbons and are discussed in Chapter VIII.

Resistance to BHC by *Boophilus* ticks appeared in most countries within a few years of its extensive employment. It was encountered originally when using high concentrations and in short-interval dipping but strains of the ticks with a very high level of resistance eventually developed, and in some areas of Australia, South America and South Africa, BHC can no longer be used for the control of *Boophilus*. Ticks resistant to BHC soon develop a resistance to the other chlorinated hydrocarbons except DDT, especially dieldrin and aldrin.

TOXAPHENE (chlorinated camphene, octachlorocamphene)

Toxaphene is virtually insoluble in water but is soluble in organic solvents. It is most commonly used as an emulsion but it has been used as a wettable powder. In an early record of its use by Legg (1949), 0.55 percent and 0.65 percent emulsions were sprayed on cattle infested with *B. microplus* and gave a complete kill of all stages of the tick; lower concentrations were also effective. This was supported by Laake (1953), who found that an 0.5 percent emulsion applied as a spray, or a 0.37 percent emulsion in a dip, gave complete protection against *B. microplus* when treatment was given at 14-day intervals. Lower concentrations employed later in Australia (CSIRO, 1953 a) gave a complete kill of *B. microplus* in field trials at strengths of 0.5 percent and 0.25 percent and had a satisfactory protective period.

Strengths of 0.5 percent and 0.25 percent are now adopted as the most suitable for general use. The stronger solution is used where a longer protective effect is needed, or for cleansing cattle before moving them from an infested to a clean area. It was originally thought that at this strength protection against reinfestation would last 10 to 14 days, but this has not proved to be the case with the two- and three-host ticks, and 7 to 8 days appear to be the longest effective residual period. The lower strength will protect against reinfestation for about 5 days.

Toxaphene has been extensively used against all species of ticks but it is probably most appreciated in Africa. Purchase (1955) states that arsenic and toxaphene are possibly the most efficient acaricides for killing all species of cattle ticks but that toxaphene is much superior to all other insecticides against *Amblyomma* and *Hyalomma* ticks.

It has been mentioned earlier that the residual effect of toxaphene has provided stockowners with a degree of protection against tick-borne

disease that was not possible with arsenic and BHC, and that several outbreaks of the disease have occurred on farms in East Africa where stockowners have reverted to the use of arsenic or BHC after having dipped in toxaphene.

The choice of toxaphene over other ixodicides is principally in areas where there is need for strict control of two- and three-host ticks and especially where these ticks may be carrying disease. There is less indication for its use against one-host ticks such as *Boophilus*, which has a long period of parasitism on the animal and is responsive to short-acting acaricides. It is valuable in the control of *Boophilus* at times of peak incidence of the larvae.

The recommended strength for dips and sprays is 0.25 percent for short-interval treatment of up to seven-day intervals, and 0.5 percent for intervals of longer than seven days, or for cleansing treatment of cattle moving from infested to clean areas.

Toxicity was described following the use of toxaphene when it was first introduced but appears to have been due largely to faulty formulation.

The United States Agricultural Research Service (1954) made a study of commercial toxaphene emulsions available at that time and found that although when fresh the oil phase was practically colloidal, even the best formulations changed after six months' use in vats and the oil particles coalesced, forming visible droplets. These droplets are more readily taken up by the hair, and a dangerously high level may be built up on the body. In the same article, the study of wettable powders containing 40 percent toxaphene was recorded: at the same concentrations used in the emulsions they gave good tick control without excessive deposits on the skin over a period of six months. Toxaphene has now been used for many years in dips and sprays without ill effect but calves under six months of age should not be treated. Dogs and cats should never be treated with toxaphene. The symptoms of toxicity are described in Chapter VIII.

Resistance to toxaphene by *Boophilus* has occurred in most parts of the world and the usual group resistance to the chlorinated hydrocarbons includes that to toxaphene. In East Africa BHC-resistant strains will usually respond to short-interval dipping with toxaphene for a considerable time.

Chlordane (Octachlorodihydrocyclopentadiene; "Octachlor")

The properties of chlordane are similar to those of toxaphene. It is insoluble in water but soluble in organic solvents. There are few records of its use against ticks and it does not appear to be available as a commercial dipping agent outside of America.

In Australia (CSIRO, 1953 a) experimental trials with an emulsion containing 0.5 percent chlordane gave a 99 percent control of *Boophilus* and a protective period of seven and a half days. At 0.25 percent it gave an 84 percent mortality and protected for six days. Limited spraying trials of chlordane at a strength of 0.25 percent over five years in Australia are reported by Legg (1956 b), when it gave as good control of ticks as did toxaphene. It has been tested in America (Brundrett *et al.*, 1955) as a 0.5 percent emulsion against *A. americanum* on cattle and compared with emulsions of toxaphene and strobane at similar strengths. All these compounds gave a practically complete kill of the tick in 48 hours and a residual protection until the fifth day.

Strobane (Chlorinated mixture of alphapinene isomers)

The chemical and acaricidal properties of strobane are similar to those of toxaphene. It does not appear to be available as a commercial dip.

Dieldrin (1:2:3:4:10:10-hexachlor-6:7-epoxy-1:4:4a:5:6:7:8:8a-octahydroexo-1:4 endo-5:8 dimenthanonaphthalene. HEOD contains 85 percent of the above compound; Octalox)

Like the other chlorinated hydrocarbons, dieldrin is insoluble in water but is soluble in organic solvents. Commercial dieldrin contains not less than 85 percent of the endo-exo-isomer.

Early tests by Legg (1950), using a 0.1 percent spray on cattle infested with *B. microplus*, killed nearly all young adults, young nymphae and larvae within 24 hours, and the older adults and engorged nymphs eventually dried up. A 99 percent kill of all ticks was achieved. Later trials in Australia (Yeerongpilly, Queensland, 1954) record that at levels above 0.05 percent it can be relied upon to kill nearly all ticks and that ticks of all stages are usually visibly affected within a few hours of the application

of dieldrin. Regular spraying of a dairy herd at 0.05 percent for three years gave results comparable to those from toxaphene and chlordane.

Dieldrin has not been widely used against cattle ticks, probably because it did not become available until BHC resistance had already appeared, and ticks resistant to BHC and other chlorinated hydrocarbons very rapidly become highly resistant to dieldrin. It has been successfully used against *Ixodes rubicundus* in South Africa and *Ixodes holocyclus* in Australia.

The peculiar property of dieldrin to spread in sheep fleece and to remain bound in the wool fibers for very long periods has caused it to be widely used to control body strike from dipterous larvae. This property does not occur in cattle and the residual effect against ticks is not unusually long. High-level resistance of *Boophilus* is recorded by Stone and Meyers (1957), when dieldrin failed to control *Boophilus* in a herd of cattle sprayed with 0.05 percent emulsion. Laboratory tests on this strain of *Boophilus* showed a median lethal concentration of dieldrin to larvae 2,000 times that of normal strains.

ALDRIN (1:2:3:4:10:10a-hexachlor-1:4-4a:5:8:8a-hexahydro-1:4-endo-5:8-dimethanonapthalene)

The commercial compound, aldrin, contains not less than 95 percent of the pure chemical. It is insoluble in water but soluble in many organic solvents. It has been applied experimentally as a spray to cattle infested with *Boophilus* in a strength of 0.1 percent (Legg, 1953) and killed all young stages, but a few adults survived to viable eggs.

Its ixodicidal and other properties are similar to those of dieldrin.

The pattern of resistance to aldrin is the same as that for the other chlorinated hydrocarbons. BHC-resistant ticks are resistant to aldrin as well as to dieldrin, toxaphene and chlordane (Norris, 1956).

The organic phosphorus compounds

In recent years a number of compounds of this group have been developed and applied to the control of larval myiasis, especially *Hypoderma* species, and also to control ticks. The advent of these compounds has been timely as a possible means of controlling ticks which have become

resistant to arsenic and to the chlorinated hydrocarbons. Original difficulties with the stability of this group of compounds in dipping vats appear to have been overcome, as several formulations are now available for use in dips.

ASUNTOL (0,0,-diethyl [3-chloro-4-methyl-7-hydroxy-coumarinyl] thionophosphate; Coumafos; Bayer 21/199; Co-ral)

Asuntol is insoluble in water but soluble in organic solvents. It is available as a wettable powder or as an emulsion. It acts as a contact poison to ticks and no systemic action appears to be involved.

Early reports from Australia (CSIRO, 1957 and 1958), using a wettable powder in a dip at a strength of 0.05 percent, showed that asuntol was highly toxic to *B. microplus* and that it was stable in the dipping vat. In South Africa, Fiedler and Veldman (1957) found from *in vitro* tests on engorged adults of various species that 100 p.p.m. killed most *Boophilus* but 200 p.p.m. was needed to kill *R. appendiculatus* and 300 p.p.m. to kill *A. hebraeum*. Trial applications of 200 p.p.m. on a bovine protected the animal from larval infestation of *Boophilus* for three days and, up to the seventh day after application, the numbers of larvae were small compared with the controls. As with all ixodicides, some of the premoulting nymphae and adults which are well protected were able to survive. It was not until the seventh day that feeding females were seen, and not until the tenth day that engorged females were present. Field trials against arsenic-resistant *Boophilus* and other species of ticks gave complete control of the *Boophilus* by the third weekly dipping in washes containing 100 and 200 p.p.m. Adults of other species were killed at 200 p.p.m. The residual effect on the bare parts of the animals lasted only a few days. Tests at 400 p.p.m. gave excellent control of all species and completely prevented the engorgement of females. The maximum nontoxic strength for dairy calves was 2,000 p.p.m., and the minimum toxic strength was 5,000 p.p.m. Preliminary tests in Great Britain on sheep by swabbing selected areas with a suspension containing 500 p.p.m., killed all ticks in 72 hours. Asuntol appears to be stable in dipping vats, since vats have been in operation in various parts of the world for over a year without deterioration.

The strengths recommended for regular field application of the suspension are 300 p.p.m. for short-interval dipping and 600 p.p.m. for long-interval dipping of ten days or longer.

Chlorthion (0,0,-dimethyl [3-chloro-4-nitrophenyl] thionophosphate)

Tests with chlorthion in Australia (CSIRO, 1957) by spraying a wettable powder at strengths of 1,000 to 5,000 p.p.m. resulted in a kill of the ticks which, at best, was only fair, and the protective period was less than three days. The cattle suffered some irritation and inflammation of the flanks and escutcheon.

Delnav (2:3-dioxane-S:S-bis [0-0-diethyl thionothiolphosphate]; Hercules 528; Bercotox)

Delnav is insoluble in water but is soluble in organic solvents. It is available as a wettable powder and as an emulsion.

In vitro tests against *Boophilus* gave a 100 percent kill of larvae at 600 p.p.m. and a 100 percent kill of adult females at 750 p.p.m. In field trials a strength of 500 p.p.m. eliminated all ticks within a few days, with the exception of some engorged nymphae. At 600 p.p.m. most nymphae were killed and at 700 p.p.m. no ticks were found alive. The residual effect at 750 p.p.m. was two to three days.

In Great Britain a dip wash containing 1,000 p.p.m. delnav gave good control of *Ixodes ricinus* on sheep for five to six weeks.

The compound is stable in dipping tanks and has been used in the field with satisfactory results in Queensland and Brazil for over two years. Some stripping of emulsions and suspensions occurs but this is controlled by topping-up at slightly higher strengths.

The recommended strength for short-interval dipping is 500 p.p.m. and for long-interval dipping 1,000 p.p.m. For single-treatment cleansing of cattle being moved from infested to clean areas, 1,500 p.p.m. is advocated.

Diazinon (0,0,-diethyl-[2-isopropyl-4-methyl-pyrimidyl-6] thionophosphate. G 24-480)

Diazinon is insoluble in water but soluble in organic solvents. Trials by Legg (1956 a) against very heavy infestations of *B. microplus* on cattle with diazinon at a strength of 500 p.p.m. gave virtually complete control of ticks of standard strains resistant to DDT. The compound was used in the form of an emulsion and was sprayed onto the cattle. Lower concentrations of 150 to 375 p.p.m. allowed very few ticks to survive. The protective effect was not longer than two days. The brief residual effect

has since been studied (CSIRO, 1958) and a marked correlation was found between the persistence and the density of the coat of the cattle, winter coats retaining an effective deposit ten times longer than the short summer coat. There was a longer persistence on stalled cattle than on cattle grazing outside, although there was no evidence of evaporation and no evidence of chemical breakdown of diazinon on cattle hair held *in vitro* at different humidities.

In stability tests in dipping vats (CSIRO, 1957) the toxicity to ticks was disappointing, although chemical tests indicated that the diazinon remained stable. More recent work shows that in emulsion form diazinon is stable and effective in vats. The recommended strengths for its use in the field are 500 p.p.m. for short-interval dipping and 1,000 p.p.m. for long-interval dipping. For single-treatment cleansing 1,500 p.p.m. should be used.

MALATHION (0,0,-dimethyl S-1, 2-bis [ethoxycarbonyl] ethylphosphorodithioate)

In Australia (CSIRO, 1955) malathion in the form of a wettable powder, sprayed onto cattle at 0.5 and 1.0 percent, gave a nearly complete kill of *Boophilus microplus* and apparent protection for about six days. Tests by Legg (1956 a) with an emulsion containing 500 and 1,000 p.p.m., sprayed onto cattle heavily infested with *B. microplus*, gave good control of DDT-resistant ticks. Used as a wettable powder suspension, it gave complete control of DDT- and toxaphene-resistant strains at 500 p.p.m. but some adults of the standard strain survived at this concentration. It gave complete control of the standard strain at 750 to 1,000 p.p.m. The residual effect was not longer than two days. It was stated in FAO Meeting Report No. 1958/24 that in the United States malathion at a strength of 500 p.p.m. provided complete kills of unfed and engorged *A. americanum* and *O. megnini* on animals and minimized the time of reinfestation to about two thirds of that when toxaphene was used.

It appears probable that the concentrations used by Legg are higher than are necessary for the control of ticks under field conditions and a strength of 250 p.p.m. appears adequate for short-interval dipping and 500 p.p.m. for long-interval dipping.

Malathion has not been greatly exploited as a dipping agent against ticks, and it is doubtful if its effectiveness is as good as other commercially available organo-phosphorus compounds.

Neguvon (L 13/59; Dipterex; dimethyl 2, 2, 2-trichloro-1-hydroxyethyl-phosphate)

Neguvon differs from the other organic phosphates, being soluble in water to 15 percent at 25° C. It is insoluble in petroleum oils but soluble in ether, chloroform and benzene. It has been applied in the treatment of internal and external parasitic infestations of animals.

There are comparatively few published records of its use as an ixodicide. In trials against *B. microplus* (CSIRO, 1958) it gave complete kill of ticks when sprayed on cattle, at strengths of 500 and 1,000 p.p.m. The protective period of the higher concentration was about five days. In a later report (CSIRO, 1959), it is said that the trials with this compound over the last season gave results inferior to those recorded above.

The toxicity is very low, as it is excreted from the body more rapidly than are the other organic phosphorus compounds.

Toxicity of all the above-mentioned organic phosphorus compounds is discussed in Chapter VIII, since all of them have a similar pharmacological action. There is a wide margin between the effective ixodicidal strength and the toxic strength, and toxic symptoms from skin application are not likely to arise.

Korlan (Ronnel; 0,0,-dimethyl-0-[2, 4, 5-trichlorophenyl] phosphorothioate) Dow ET-57

There is as yet little information about this compound in tick control, but Drummond *et al.* (1960) report that 0.75% Ronnel was as effective as 0.5% toxaphene on *Amblyomma americanum* one week after treatment.

There is one member of an unrelated group of ixodicides - the carbamates - which must be mentioned, although as yet it has not been fully tested against ticks.

Sevin (N-methyl-1-naphthyl carbamate)

Drummond *et al.* (1960) report that 0.5% Sevin caused a greater reduction of *Amblyomma americanum* on cattle than did 0.5% toxaphene. Drummond *et al.* (1959) also tested Sevin, together with a number of ixodicides, against the *Dermacentor albipictus* in naturally infested cattle. At 0.5%, it was more efficient than 0.5% toxaphene, which was taken as the standard, but at 0.25% and 0.1%, it was less efficient.

VI. DETERIORATION AND DEPLETION OF IXODICIDAL WASHES AND ESTIMATION OF THEIR CONCENTRATION

Various changes may take place during the use of ixodicides in dip washes, whereby their efficiency is lowered or lost. The term deterioration is used here to describe changes of a chemical nature, in which the active principle is changed to an inactive form. The term depletion is used for physical changes which either render the active principle unavailable or cause it to be selectively removed from the dip wash.

Deterioration is a recognized problem in dip washes containing arsenic or BHC and may have been involved in the failure of some of the organic phosphorus compounds when they were first used.

Sodium arsenite can become oxidized to the less active sodium arsenates by bacterial action. The process involves a specific arsenite dehydrogenase system and *Pseudomonas* bacteria are known to be involved. Oxidation can be arrested by the addition of potassium cyanide at the rate of 1 $^1/_2$ pounds per 2,500 gallons, but a cheaper and more effective treatment is the addition of sugars, which reverse the oxidation process and cause the reduction of the already oxidized arsenates back to sodium arsenite. The cheapest form of sugar for this purpose is molasses (Cohen, 1947). Arsenical solution is normally very stable when weekly dipping is practiced and when fairly large numbers of cattle are dipped, because of constant addition of fresh arsenical solution needed to replace that removed by the cattle. When dips are used only infrequently or become excessively fouled, chemical oxidation is likely to occur.

The oxidative change is not detected by the routine test for arsenical strength, which only detects sodium arsenite, and there is thus a danger of toxicity and scalding, because the test will indicate an understrength dip. A test for total arsenic, in addition to the routine iodine test, will show the extent of the oxidative change.

Deterioration of BHC in dipping tanks is recognized but there is not yet agreement on its nature, although it is fairly certain that the active gamma isomer becomes changed with consequent loss of biological effi-

ciency. Allan (1955) associates the change with the growth of anaerobic organisms, the hydrogen they produce probably causing dechlorination of the gamma isomer. Roulston and Schunter (1958) say that bacteria are not the cause, although the loss is favored by the presence of dung and urine and also by increased temperature and increased pH, with little loss at values below pH 5. The increase of pH occurred principally in the sludge which settled in between dippings, and these authors conclude that this is where most of the chemical change takes place. Control of the pH of the wash might control the loss of gamma BHC. The difference of opinion on the cause of the loss of efficiency may mean that more than one chemical change is involved in the loss of gamma isomer. Chemical analyses for BHC in dip washes normally detect only total BHC and will show adequate strengths when the biological efficiency is lost. Gamma isomer can be analyzed by paper chromatography, and this is accepted by most workers but, according to Graham (1956), variable results are obtained on the same sample when analyzed by different chemists, and biological efficiency may be maintained even where a considerable loss of gamma isomer is shown.

Deterioration is not likely to occur with short-interval dipping, especially when fairly large numbers of cattle are being dipped. Where a high concentration of gamma isomer is used in the dip, it is unlikely that deterioration will be such that ticks will not be controlled, but where low concentrations are used and dipping is not frequent, then deterioration may be sufficient to cause failure of tick control.

Depletion may be of two kinds: the first is a fairly constant feature of suspensions and emulsions in dips and is known as selective adsorption or stripping; the second involves physical changes in the particle size, resulting in "settling out" of the active principle.

The mechanism of selective adsorption, stripping, or exhaustion of dips is not properly understood, but it is probably caused by the specific adsorption of the suspended particles or globules on the hair and skin of animals passing through the wash. The effect is one of filtration and the fluid draining from the animals contains less ixodicide than did the original dip fluid. The continuous removal of the active agent would result in a progressive lowering of the dip strength, as was noted in Chapter V in the discussion on BHC. Replenishment of the dip fluid is therefore at a higher concentration than the original strength of the fluid in the bath, or else the bath is filled and replenished at strengths much higher than the minimal effective concentration.

"Settling out" of dip suspensions is a normal process, no matter how fine the suspension and the quality of the dispersing agents; it occurs to a lesser extent with emulsions. Even with the very fine particles used in suspensions and after proper agitation, about 50 percent of the particles will have settled out in an hour after the suspension has been freshly made up. In dip tanks the contaminating particulate matter adsorbs the chemical particles and some aggregation of the particles also occurs, with the result that the larger particle size settles out more rapidly. Dingle (1956) gave figures for the sedimentation rate of DDT (0.56 percent colloidal) and BHC (0.05 percent suspension) in a dipping tank. After thorough mixing by dipping cattle and then leaving the wash to settle, the DDT fell below the effective level (0.3 percent) in 30 minutes, and the BHC fell below the safe level in 30 to 60 minutes. Sedimentation rates can be more rapid than this, and if the wash strength is near the minimum level and dipping is held up for any reason, it is unwise to allow the dip to stand for more than 10 to 15 minutes before dipping is resumed, without thorough mixing, as is done at the beginning of the dipping. The stripping and settling effects of BHC in dips is well described by Norris *et al.* (1950).

Changes of a more permanent nature can occur and result in the particles becoming unavailable to the animals. The permanent heavy sedimentation at the base of the plunge wall has already been referred to, and physical changes can occur, with caking of the suspension so that it fails to disperse even with thorough mixing. The hardness of water, especially if due to the presence of sodium chloride, can affect emulsions based on sodium soaps. The breaking of such emulsions can result in high concentrations of the ixodicide floating to the top in the oily solvent and consequent danger of poisoning stock. Good miscible oils, in which synthetic emulsifiers are employed, will mix satisfactorily with waters containing much sodium chloride or which are very hard from other causes.

Great care must be taken that different commercial preparations of emulsions or suspensions are not mixed, for many are incompatible, but the makers can advise which preparations can be mixed. It is also essential to follow the maker's instructions in the mixing and maintenance of the dip fluid.

Finally, changes may take place within the containers of dip concentrate due to age or extremes of heat or cold, and old containers of dip are best referred to the makers before use.

It is not proposed to discuss the details of the methods of chemical analysis used in testing the strength of dips but only to point out their limitations and to indicate which dips may be tested on the farm.

The first consideration is the taking of the sample to be tested. Samples must be representative and the dip must first be thoroughly agitated. The usual procedure is to take the sample immediately the last animal has passed through the dip and from a point centrally in the dip. A 1-pint household bottle is usually used because it is available on the farm, but it is better for testing laboratories to send out bottles of known chemical cleanliness and to insist on their being used. A wooden container with a long handle is needed to hold the bottle and to immerse it about 3 feet below the surface. If the neck of the bottle is fairly narrow and the bottle is plunged quickly below the surface, very little fluid will enter until it is at the required depth. There is some valid reason for using a wide-mouthed bottle to ensure that there is no selection or retention of particulate matter, but if a wide-mouthed bottle is used, an appliance must be made so that it can be immersed upside down and then inverted when it has reached the required depth.

Arsenical dips can be tested on the farm by titration against a standard iodine solution. Simple kits containing the apparatus and the test solution are available, together with conversion tables, so that the titration can be directly related to the quantity of dip concentrate needed for replenishment or reinforcement. The limitation of the test concerning its inability to detect inactive sodium arsenates has already been discussed.

The testing of the chlorinated hydrocarbons is usually done by the dehydrochlorination of the chemical and the titration of the freed chloride. It is a somewhat laborious procedure and requires the facilities of a chemical laboratory. This test will not differentiate active from inactive isomers and will, therefore, not detect loss of biological efficiency due to loss of gamma isomer in BHC dips. Gamma isomer can be determined by paper chromatography but this is not a method available in routine dip-testing. A vat-side test for toxaphene has been devised which utilizes an organic solvent to extract the toxaphene from the dip sample and measures the quantity by the change in specific gravity of the solvent. The test appears to be reasonably accurate.

Laboratory analytical methods are available for the organo-phosphorus dips. These methods are fairly complicated and no vatside test is available.

VII. RESISTANCE OF TICKS TO IXODICIDES

The control of ticks and tick-borne disease of livestock is presenting veterinarians with similar problems of resistance that the public health authorities have met in the control of the various insects of public health importance.

Resistance of ticks to ixodicides has reached significant proportions only in one genus of ticks, namely, *Boophilus*; but it has been recorded for *R. sanguineus* (Hansens, 1956), and very recently for *R. evertsi* (Whitehead and Baker, 1960). From the widespread occurrence of resistance in insects of agricultural and medical importance, it is almost certain that sooner or later ticks of other species will develop resistance.

Resistance to ixodicides is the development in a strain of ticks of an ability to tolerate doses of toxicants which would prove lethal to the majority of individuals in a normal population of the same species. This definition presupposes the existence of a quantitative test by which to compare strains, and this will be discussed later in this chapter. By testing various strains or sources of the tick species, the physiological range of resistance can be determined. This has not been extensively applied to ticks, and more precise and co-ordinated tests are needed. In medical entomology, at least for houseflies, a resistance to five to ten times the amount needed to kill normal strains is held to constitute resistance. Resistances of two to four times the median lethal dose for normal strains is defined as tolerance. Tolerances of this order, usually resulting from insecticide pressure but not involving any specific defence mechanism, have been termed "vigor tolerance" by Hoskins and Gordon (1956). Vigor tolerance is a strain selection found in the extremes of environmental conditions and insects survive because of a more robust constitution. Their physiological mechanisms are perhaps better able to substitute for physiological mechanisms injured by the insecticide. Field strains of insects are often more tolerant to insecticides than are laboratory strains, and

as Brown (1950) has pointed out, this exaggerated susceptibility of laboratory strains, which may well be due to lack of vigor tolerance, could give a false impression of resistance being present in the field. For instance, field strains of houseflies from remote untreated regions in Quebec were ten times more tolerant to DDT than the normal laboratory strain (Roadhouse, 1953).

Behavioristic resistance is recognized in some insects and it comprises the development of the ability to avoid a dose of insecticide which would prove lethal. This is not likely to exist among ticks.

The mode of development of resistance is one of selection and is not an acquired tolerance. It cannot be induced by exposing normal strains to concentrations of insecticide which fail to kill any of the organisms, although resistance to DDT has been induced in *Pediculus* which were reared in contact with an amount of insecticide sufficient to cause a very low mortality (Eddy *et al.*, 1955). Insecticides do not increase genetic mutation but the genetic factors for resistance are present in low frequency before the insecticide is applied, and by selection the gene frequency for resistance in the population is increased.

The physiological mechanisms have been studied in insects and some of these mechanisms are understood. There has been very little work done on the mechanisms of resistance of ticks but they are assumed to be similar to those of insects. Resistance of *Boophilus* to arsenic, which was the first type of resistance encountered, has no genetic or physiological relationship to resistance to any of the other ixodicides. It is significant that the development of resistance to arsenic occupied more than 25 years, but having done so, these resistant strains became resistant to BHC within two years (Whitnall *et al.*, 1952).

In insects, two types of resistance to the chlorinated hydrocarbons are recognized: one for DDT; and a second against the other hydrocarbons such as BHC, dieldrin, aldrin, toxaphene and chlordane. These two groups have been shown to have separate toxicological, biochemical and genetic characters. According to Norris (1956) the pattern of resistance in *Boophilus microplus* closely parallels that of the housefly, BHC-resistant ticks being resistant in some degree to toxaphene, dieldrin, aldrin and chlordane; but no BHC-resistant strain has been shown to be resistant to DDT. Likewise DDT-resistant strains are susceptible to the other hydrocarbon group. More recently, Stone and Webber (1960) have reported a strain resistant to both DDT and the BHC - dieldrin group.

In DDT resistance, an enzyme system involving a DDT hydrochlorinase has been demonstrated in insects. Kelthane is a DDT-type molecule which is not dehydrochlorinated by insects, and it is agreed that if DDT resistance in ticks depends on enzyme dehydrochlorination, then kelthane should be equally toxic to DDT-resistant and DDT-susceptible strains. Preliminary tests (CSIRO, 1957) suggest that this is so but neither DDT hydrochlorinase nor the breakdown product, DDE, has been found in either the susceptible or the DDT-resistant *B. microplus* (Roulston and Schnitzerling, unpublished data), so resistance in this species would appear to depend on a different defence mechanism.

It is unlikely that DDT resistance is a simple phenomenon of enzyme degradation and other contributory mechanisms have been suggested.

Relatively little is known about the essential mode of action of other chlorinated compounds or of arsenic on ticks.

The history and distribution of resistance in *Boophilus* is of interest, since the process has been essentially similar in widely separated parts of the world. Arsenic was the original ixodicide used to control ticks and it gave excellent control for 20 to 30 years. In 1937, arsenic-resistant ticks were found in South Africa, Australia, and at about the same time in South America. In South Africa resistance was originally confined to a small focus (Du Toit, Graf and Bekker, 1941) which extended over the subsequent eight to ten years, until it covered most of the eastern zone. There is no such history in Australia, where the picture is one of increasing frequency of resistance but in a random fashion over most of Queensland. No detailed history of the development in South America is available.

The occurrence of arsenic-resistant *Boophilus* strains became a serious problem in each of the three countries until the introduction of BHC and DDT, around 1946. In Argentina an eradication program which had been in operation for six years was hampered by arsenic resistance (Boero, 1953) but this was eventually overcome by the use of BHC and toxaphene. In South Africa BHC was originally employed at the rate of 50 p.p.m., whereas in Australia it was used at 500 p.p.m. Resistance to BHC was observed in South Africa 18 months after its introduction, and in Australia in about two years, so that the large difference in dosage level does not appear to have made an important difference in the rate of development of the resistance. In South Africa resistance first appeared in the same place where arsenic resistance had first occurred, and the subsequent increase in the area involved followed much the same pattern as with arsenic. Arsenic resistance was not essential to the development of

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BHC resistance, as was shown by Bekker (1953), who describes a BHC-resistant strain in an area far removed from the original but by now an extensive BHC-resistant zone. This strain was still susceptible to arsenic.

DDT became the principal ixodicide for the control of resistant *Boophilus* in all countries, but in South Africa, where the two and three-host ticks were poorly controlled by DDT, it was necessary to use mixtures of DDT and arsenic, or one of the chlorinated hydrocarbons to control the other tick species.

By 1949, in South Africa (Whitnall *et al.*, 1952) the ticks in the East London area showed very considerable resistance to BHC and toxaphene, as judged by their effect on adult females, of which only 5 percent of treated ticks failed to lay viable eggs. The females were still susceptible to DDT but they were still highly resistant to arsenic despite their lack of contact with it for four years.

For the next few years control everywhere was largely dependent on DDT, but arsenic, BHC and toxaphene were still being employed, the use of BHC being presumably due to the higher concentrations being used and the relative susceptibility of the larval stages. Hitchcock (1953) showed that while the adult females and the larvae were both about 180 times more resistant to BHC than were susceptible strains, the larvae could still be killed by 22 p.p.m., whereas 7,400 p.p.m. only gave 50 percent control of the adult females.

DDT resistance appeared in South Africa in 1956 and adult females had an L. C. 50, which was 13 times greater than in normal strains (Whitehead, 1956). DDT resistance was reported from the field in Australia in 1954-55, and was confirmed experimentally by Legg *et al.* (1955), and later, another DDT strain was investigated by Stone and Meyers (1957), who found the larvae had a median lethal level 22 times that of a normal strain. DDT resistance remained at a sufficiently low level to enable control to be achieved by frequent dipping at high concentrations (CSIRO, 1957), and it has been a character of DDT resistance everywhere that the level of resistance is low, as it was with arsenic.

The progressive development of resistance to ixodicides in East Africa was similar to that in other parts of the world.

It is difficult to portray with any clarity the present situation in the *Boophilus*-resistant areas. The record of resistance in a country does not mean that ticks over the whole country have become resistant and that the chemical is no longer employed. In all countries arsenic is still a

commonly used ixodicide, despite the fact that 20 years have elapsed since ticks became resistant to it.

Once resistance has appeared, the extent of its distribution tends to increase either by dissemination of the original resistant strains or by the continued chemical pressure which created the first pockets of resistance; this extension, however, has not been uniform or absolute. Where resistance occurred, recourse was made to alternative ixodicides, to which, in turn, resistant strains developed. Most countries did not restrict the freedom of individuals in their personal choice of ixodicide, except where control schemes were in operation, and there was, undoubtedly, indiscriminate and patchy use of the newer ixodicides, either because they were new and thought to be better, or because the previous ixodicide was failing to control the ticks. There is no evidence that this uncontrolled use of ixodicides hastened the development of multiple ixodicide resistance. The pattern of development of resistance in South Africa, where there were strict regulatory measures governing the type and concentration of ixodicide which could be used in dips, is not greatly different from that in countries where no such control was in operation.

The complexity of representing the extent and degree of resistance in any country is probably best illustrated by the single example of a strain studied in Australia by Norris and Stone (1956). In four herds, toxaphene at 0.5 percent was failing to control *B. microplus* but in an adjoining herd it achieved good control. Toxaphene resistance of the order of 19 times that of normal strains was proven in the four herds which had a previous history of BHC resistance. Spraying tests with 500 p.p.m. BHC proved that BHC resistance still existed, as the ticks were unaffected by it. Spraying trials of the toxaphene-resistant cattle showed no resistance to arsenic, DDT or diazinon, but the ticks were resistant to lindane, dieldrin and aldrin given by the subcutaneous route.

The situation is likely to become even more confused in a few years, since the ticks, resistant to the chlorinated hydrocarbons, are now being attacked with the organic phosphates, and since other insects have developed a resistance to this group, there is every reason to anticipate that it will not be long before ticks also become resistant. Despite its patchwork distribution, there is some order or grouping of the chemicals to which resistance has occurred. This will be described later, when the methods for dealing with resistance are discussed. Before doing this, the resistance in ticks other than *Boophilus* must be examined.

Hansens (1956) describes a serious infestation of dogs with *R. sanguineus* in kennels which, during the previous six or seven years, had been kept free of ticks by spraying the kennels with 2.0 percent chlordane from 3 to 12 times a year. Three applications of 3 percent chlordane to the kennels within a week, and the dipping of the dogs in 2 percent chlordane, failed to clear the ticks. Rather surprisingly, the infestation was cleared by treating the kennels with BHC, but at the high concentrations of 2,500 to 5,000 p.p.m. on the buildings and washing the dogs in 450 p.p.m.

A few years later, Hazeltine (1959) sampled the dog population of the same area by random collections of engorged females from dogs. There was a wide range of susceptibility to BHC at 500 p.p.m., varying from insusceptible to completely susceptible, but most were susceptible. There was a uniform but extremely low level of susceptibility to chlordane.

It is significant that resistance in a three-host tick should first arise in a species where there was opportunity for long contact with the ixodicide by the treatment of buildings, as it is becoming increasingly reasoned that in control measures in buildings against insects, insecticides having a long residual action will exert selection for a long time and will, therefore, more rapidly give rise to resistant populations. For this reason, Henderson (1955) has suggested that the insecticide chosen for malaria control should be one whose activity deteriorates rapidly at the end of the transmission season.

The recognition of resistance in a tick population is not as simple as it would appear. Graham (1956) notes that failure to control ticks in the field may be due to depletion of wash strength, an unsatisfactory program, or resistance of the ticks. The first two reasons are more common than the third. Most field workers will support this statement. Other factors which can give semblance to resistance are seasonal rises in tick numbers due to climatic factors, the stocking rate or grazing area may have been changed, a different type of ixodicide with a slower rate of kill may have been used, and a different person may be assessing the tick burden.

All these reasons must be checked before examining the tick strain. If the dip wash is suspect, chemical analyses can be made but this may be misleading; even if the chemical level is found to be correct, there may be loss of biological activity. Most owners will not wish to empty a dip tank and refill it simply to answer this question, but if ten test animals out of the herd can be thoroughly sprayed with freshly made wash by means of a hand pump and then allowed to run with the rest of the herd, a com-

parison of the tick burden on these cattle with that on those dipped in the tank will indicate whether the wash is at fault. If the wash is not at fault, then a laboratory susceptibility test can be carried out. This test spraying gives a quick, rough test of resistance and eliminates the need for the unnecessary performance of biological tests which, apart from being laborious and not readily available to the farmer, take a long time to produce an answer.

Laboratory tests of ticks are not yet uniformly standardized but the general procedure is similar in most testing centers. Adult engorged females which have just dropped from the host and young larvae of the strain to be tested, together with a known susceptible strain and a known resistant strain, are subjected to immersion in test fluids of strengths above and below the median lethal concentration. The fluids must be at a standard temperature and immersion is done for a standard time. Sometimes test fluids may be injected into the females and sometimes fixed quantities may be deposited on the body surface. The females are afterward held under optimum conditions and the numbers dying and ovipositing and the viability of the eggs are recorded. The death or survival of the larvae is recorded and the results are usually registered by probit analysis as a regression curve, and from this the 50 percent mortality (L. D. 50 or L. C. 50) is obtained. By comparing the L. D. 50 and the results of the viability tests of the egg clusters of the strain with those of a standard susceptible strain, the degree of resistance of the strain is determined.

A fuller discussion of the subject of the testing of ticks for resistance is given in Appendix A of FAO Meeting Report No. 1958/24, and an excellent review of the whole field of insecticide testing is given by Busvine (1957).

Having established the occurrence and degree of resistance, the following procedures are available to deal with the ticks:

(*a*) *The concentration of the ixodicide in the dip wash can sometimes be raised.* This cannot be done so readily now, as most ixodicides are used at or near their economic or biological maximum strengths. It certainly cannot be done with arsenic solutions which are issued at or near their maximum toxic safety limits in normal dips. Dip strength can often be successfully increased in the case of DDT, where resistance is of a low order, and even with resistant strains, lethal limits for the larvae are attainable, especially if the wash strength has been at the rather low level of 0.1 to 0.2 percent, as is employed

in some dip tanks. Resistance to the chlorinated hydrocarbons such as BHC is usually of a high order and, while increasing the strength may cause a temporary reduction of the ticks, they soon adapt themselves to levels which are uneconomic.

Raising the dosage level of the ixodicide to a tick population which is showing evidence of resistance will result in firmly establishing a population with a high degree of resistance, which may induce increased tolerance of a specific or nonspecific nature to other ixodicides. For this reason, raising the ixodicide level should never be undertaken in large-scale control schemes but instead, a switch should be made to an unrelated ixodicide at the first sign of resistance.

(*b*) *The frequency of the dipping interval can be increased.* The larval stages of resistant strains are often still responsive to normal dip strengths, and if long-interval dipping has been employed, a change to short-interval dipping may therefore control the larvae for a considerable time and thereby control the tick population. Increased frequency of dipping may be combined with increased dip strength.

(*c*) *The addition of another ixodicide.* Where three-host ticks occur together with *Boophilus*, the ixodicide to which *Boophilus* has become resistant will still effectively control the three-host ticks. In South Africa and other parts of Africa the addition of DDT or an organophosphorus agent for the purpose of controlling *Boophilus* is a rational procedure, since DDT alone will not control the three-host ticks and the original ixodicide alone will not control the *Boophilus*. Other than this example there is very little justification for employing mixtures of ixodicides to control resistant ticks, unless there is a true synergism between the components of the mixture. There is no theoretical justification for using a mixture of ixodicides in order to reduce the chances of producing a resistant strain.

(*d*) *Change of ixodicide.* The logical course of action against resistant ticks is to change the ixodicide to one of proven effectiveness and which has a different physiological or chemical action. There are four groups of unrelated compounds presently available, namely, arsenic, DDT, chlorinated hydrocarbons and organic phosphates. Ticks initially resistant to one or more of these groups will respond to any of the others. Even within the chlorinated hydrocarbons, there may be some immediate response, but resistance will rapidly

develop. BHC-resistant ticks quickly build up high-level resistance to dieldrin and aldrin but control may be effected for some time with toxaphene or chlordane. The new ixodicide should be employed at the highest safe and economic concentration.

(*e*) *Alternation of acaricides has been suggested as a means of delaying or reducing the chances of the onset of resistance.* It was proposed by Coyne (1951) for malaria control and in Argentina (Argentina, 1956) it was claimed that changing the dipping fluid every six months and alternating between sodium arsenite and chlorinated camphene would delay the onset of resistance in *Boophilus*. The theoretical grounds for this procedure are slightly in favor of doing so but little experimental work has been carried out to substantiate it. There is no hope of being able to return to dip fluids which the ticks have resisted in the past and whose use has been discontinued for that reason, even if several years have elapsed since they were last used, as resistance returns within a generation. If ixodicides with a negative correlation could be found, i.e., an ixodicide which is more toxic to a resistant strain than to a normal strain, then alternation would be effective; but in the existing state of knowledge, it is probably unwise to adopt alternation of ixodicides, as it is not known how important is the effect of selection pressure of one group on other unrelated groups.

(*f*) *The evidence and experience from the control of insects of medical importance shows that insect resistance is one of the greatest handicaps to long-term control schemes.* Control or eradication must conserve the use of the different effective acaricides and utilize every possible means of biological control.

VIII. TOXICITY OF IXODICIDES

Arsenic

Toxicity from arsenic usually results from ingestion of dip wash or residues from the dip or dip containers, but local skin damage and systemic toxicity can occur from the presence of arsenic on the body surface. The latter may arise when cattle are dipped for the first time in arsenic, and cattle should therefore be introduced into a lower strength arsenical solution or be dipped at 14-day instead of weekly intervals for the first few times. Surface scum on the dip wash may contain a high concentration of arsenic and cause local scalding. Surface scum should always be skimmed off before dipping commences. Skin damage or scalding is likely to occur under too slow or too rapid drying of the animals after dipping; thus hot, humid days or intense sunshine should be avoided. Most commonly, it occurs in sites of the body which are subject to chafing and moistness, such as inside the legs and on the sides of large udders in dairy cows, and on the scrotum of bulls. These sites can be protected by treating them with an emolient grease before dipping is carried out.

Systemic toxicity may be acute, subacute or chronic, depending on the quantity of arsenic absorbed. Acutely affected animals are usually found dead or in too advanced illness to respond to treatment, but the subacute and chronic cases can be successfully treated: $^1/_4$ to 1 ounce (7 to 30 grams) of sodium thiosulphate is given by mouth in half a pint (0.3 liter) of water, and the dose is repeated every half hour for the first few hours and every four to six hours for the next 24 hours. Intravenous injections of 5 to 10 grams of sodium thiosulphate in a 5 percent water solution is essential in the more acute cases, especially where the beginning of treatment has been delayed. The intravenous injection can be repeated every four hours. Horses require the same dose as cattle, and sheep and

goats are given one quarter of the cattle dose. Recent scalding of the skin is treated with 5 percent sodium thiosulphate solution and, afterward, with emolient ointments, and the animal must not be dipped until the lesions are healed.

Diagnosis of acute and subacute fatal poisoning is easily determined by laboratory analysis of the wall or contents of the abomasum. Chronic poisoning is less readily diagnosed and liver analysis is the most satisfactory method.

Chlorinated hydrocarbons

The toxic action is primarily on the central nervous system and the symptoms range from depression to nervous excitement and convulsions, depending on the dosage. Muscle tremors and twitching are fairly constant symptoms, usually with some excitability. In more severe cases, these symptoms can progress to convulsions which can be immediately fatal, but repeated seizures often occur before ending in death or, less frequently, in recovery. Death is due to respiratory paralysis and therefore it is not easy to determine the cause of death from post-mortem examination, but the clinical history is a useful guide. The commonest lesions are congestion and edema of the lungs, subepicardial hemorrhages, and palor of the viscera and musculature. Deaths of stock following dipping are not common and are usually due to physical breakdown of the emulsions, causing excessive deposits of the chemical on the skin. Very few fatalities are recorded from the use of DDT, as it is nontoxic at levels very much greater than those employed in dipping practice. Roulston *et al.* (1953) reported two experiments in which steers and heifers were treated weekly with 22.5 grams of DDT dissolved in peanut oil rubbed on their backs. There was no evidence of toxicity, although fatty tissues in some of the animals contained up to 425 p.p.m. of DDT. Radeleff *et al.* (1955) later sprayed calves one to two weeks old with 8 percent DDT and also with its analogues, DDD and methoxychlor, without producing any signs of toxicity. Toxicity of DDT to horses has been met with in Australia by Jackson (1956); it took the form of a nonfatal sensitivity, with respiratory embarrassment and discharge from the eyes and nose but the condition was due to the DDT solvent, brinol, and not to the DDT itself. In the same journal, Mulhearn (1956) says that he had encountered skin sensitivity in racehorses following DDT treatment but he had never encountered the respiratory sensitivity.

Toxicity following the normal use of BHC has not often been recorded, although, according to Radeleff (1958) the toxic level in young calves given in Table 2 is 500 p.p.m., which is the amount used in dipping, and one might have expected instances of toxicity in them. Legg (1956 b) says that at times BHC has produced serious illness and mortality in cattle in Australia. It has occurred in one mob of cattle when others dipped at the same time were unaffected, and in dip tanks which had been used for a long time, without trouble. He associates the incident with hot weather and drought. Radeleff and Woodard (1956) experienced mortality in sheep in somewhat similar circumstances in Texas, when nearly 500 out of a flock of 1,000 died after being dipped in BHC at 600 p.p.m. Emaciation and lactation were regarded as the reason for the susceptibility as, until that time, nearly 2 million sheep had been dipped in Texas, without fatalities. The toxicity of toxaphene to young calves is recognized, and it is not usual to dip calves when under six months of age, although some people regard three months as a safe age at which to dip them. Fatalities or toxic symptoms in dogs are not uncommon from accidental or deliberate contact with cattle dips containing toxaphene, either by immersion or by mouth. The toxic dosage for domestic stock of the commonly used hydrocarbons has been summarized by Radeleff (1958), and as a guide to their use in dips, his table, giving the toxic and nontoxic doses when applied as sprays, is given in Table 2.

TABLE 2. — Toxic and nontoxic doses applied as sprays

Chemical	Animal	Age	Maximum nontoxic dose tested	Minimal toxic dose found
			. . . *Percentage*	
Aldrin	Calves	1-2 weeks	0.1	0.25
	Lambs	3 weeks	—	4.00
BHC gamma	Calves	1-2 weeks	0.025	0.05
	Calves	6-8 months	0.15	—
	Cattle	adult	0.1	0.25
	Lambs	6 weeks	1.0	—
	Sheep	adult	1.0	—
	Pigs	3 months	1.0	—
	Horses	adult	0.15	—

TABLE 2. — Toxic and nontoxic doses applied as sprays (continued)

Chemical	Animal	Age	Maximum nontoxic dose tested	Minimal toxic dose found
			. . . . Percentage . . .	
Chlordane	Calves	1-2 weeks	0.50	1.0
	Cattle	adult	2.0	—
	Lambs	3 weeks	1.0	2.0
	Sheep	adult	3.0	4.0
	Goats	adult	3.0	4.0
	Horses	adult	1.5	—
Dieldrin	Calves	1-2 weeks	0.1	0.25
	Cattle	adult	1.0	2.0
	Lambs	2 weeks	2.0	3.0
	Sheep	adult	—	4.0
	Pigs	8 weeks	4.0	—
	Goats	adult	—	4.0
	Horses	adult	1.0	—
Toxaphene	Calves	1-2 weeks	0.5-0.75	1.0
	Cattle	adult	2.0	4.0
	Lambs	6 weeks	4.0	—
	Sheep	adult	1.5	4.0
	Goats	adult	1.5	4.0
	Pigs	adult	4.0	—
	Horses	adult	1.5	—

The treatment of poisoned animals is symptomatic. If poisoning has resulted from skin application, the chemical should be removed as quickly as possible by washing the animal thoroughly in warm, soapy water. The tremors and excitement are controlled by narcotics, especially the barbiturates; they can be given intravenously to acutely affected animals, which should be kept warm and free from disturbance.

There are certain toxic hazards to human beings, either from direct contact with or from the residues present in the tissues of dipped animals.

There is not much danger from contact with the dips, but in handling some of the dip concentrates, it is desirable that gloves be worn. Residues of many of the chlorinated hydrocarbons are known to occur in the animal or the animal products when animals have been regularly dipped in them but it is not known at what levels these residues may be toxic to man. The view is adopted in the United States that there must be no residues present in the milk, and this makes it impossible to use many of the chlorinated hydrocarbons on dairy cows but several, particularly toxaphene, are used on beef animals. Most other countries recognize the possible danger of residues but have not been able to restrict their use, because if these dips were not used, there would be no animals or animal products.

Only small amounts of the order of 1-2 p.p.m. are excreted in the milk but fairly large quantities may be built up in the body tissues, mostly in the fat. Levels of 80 to 90 p.p.m. of DDT are attained from absorption after dipping or spraying but this amount does not increase appreciably with prolonged regular dipping. Aldrin and dieldrin both give residues in the body tissues and in milk but the aldrin is converted and stored as dieldrin in the animal.

The organic phosphorus compounds

The pharmacological action of this group of compounds in mammals is the inhibition of cholinesterase. Lowered levels of this enzyme system can be measured by laboratory tests on the blood, and considerable depression of the system can occur before toxic symptoms become evident.

The symptoms of poisoning are salivation, constriction of the pupils, diarrhea and sweating, followed by dyspnea due to bronchial constriction. Stiffness of the limbs causes the animal to move with its legs extended rigidly and, in severe cases, it may fall when trying to walk.

Post-mortem lesions are slight and are not pathognomic. Radeleff (1958) gives the toxic levels of the various organic phosphorus compounds when applied as sprays, shown in Table 3.

TABLE 3. — Toxic levels of various organic phosphorus compounds applied as sprays

Chemical	Animal	Acaricide in spray or dip		
		lethal	toxic	nontoxic
		Percentage		
Parathion	Calves	0.02	0.01	—
	Sheep	1.0	—	—
	Goats	1.0	—	—
Diazinon	Calves	0.25	0.1	0.05
Delnav	Calves	0.5	0.25	0.1
	Yearlings	—	—	0.5
Asuntol	Calves	0.75	0.5	0.25
	Cattle	—	—	2.0
Malathion	Calves	1.0	—	0.5
	Cattle	—	—	2.0
	Turkeys	—	—	5.0
Neguvon	Calves	—	—	1.0

Toxic hazards to man have been emphasized by Barnes *et al.* (1957). They note that because of DDT resistance in mosquitoes and flies, this chemical may be replaced by the organic phosphorus insecticides. Their use under the conditions where DDT has been safe might be dangerous to the men who apply them. Caution must be taken in handling dip fluids and gloves should be worn, especially for the dip concentrates.

The organic phosphorus compounds are not readily absorbed from the skin of cattle and the absorbed products are metabolized rapidly and excreted, principally in the urine, as water-soluble metabolites and degradation products. Tests with malathion by March *et al.* (1956), using P_{32} labelled chemical, showed very small residues of malathion metabolites in the meat, of the order of 0.05 to 0.15 p.p.m., and slightly higher residues of 0.2 to 2.0 p.p.m. in some of the other tissues. There was no

detectable unchanged malathion in the tissues or muscles. Claborn *et al.* (1956) sprayed cattle 16 times at weekly intervals with 0.5 percent malathion, and fat samples taken one week after the last spraying showed no detectable amounts of the ixodicide. Four dairy cows, sprayed twice in one week with 0.5 percent or 1.0 percent, had 0.08-0.36 p.p.m. in the milk 5 hours after spraying. After 24 hours, only traces were present, and after three days the milk was free. Because of the excretion in the milk, malathion is not recommended for use on dairy cows in the United States but it is permitted on beef cattle (Knipling, 1958).

Treatment of poisoning with the organic phosphorus compounds is the administration of large doses of atropine sulphate, up to 0.5 milligram per kilogram for cattle. Part of the dose should be given intravenously in acute cases. Woodard (1957) records the value of 2 P.A.M. (2 - pyridime aldoxine methiodide), in conjunction with atropine, in the treatment of poisoning by parathion and diazinon.

IX. SUMMARY

Objectives and purpose of tick control

The objectives and purpose of tick control are threefold: (*i*) mitigation of tick worry or tick-borne disease; (*ii*) eradication of ticks or tick-borne disease; (*iii*) prevention of the introduction of ticks or tick-borne disease.

Mitigation of tick worry or tick-borne disease

The existence of tick-borne diseases must be established and their incidence and distribution determined. The economic importance and even the very occurrence of disease may be difficult to prove in scrub stock, where the disease is enzootic. Tick worry and damage is more readily apparent even to the untrained observer. Therefore, the first step is the provision of veterinary and biological staff to determine the nature of the tick-borne diseases, the species of ticks present and their biology, and the ability of the various tick species to transmit disease.

The existence of tick-borne diseases and their method of spread must be made known to stockowners. The advantages of tick control must be advertised via demonstration centers, publicity, and extension work by veterinary and agricultural staff.

All the means of applying ixodicides should be obtained and put into operation, to enable stockowners and technical advisers to become familiar with the constructions and operations, and to test the advantages and disadvantages of the different types of ixodicides. Ixodicides should also be tested, as local conditions may render chemicals or their formulations unsuitable for particular conditions. Staff must also be trained in the maintenance and testing of wash strengths.

Individual owners should be encouraged to start hand spraying and perhaps loans afforded to communities to build dips or sprays, and staff trained to operate them. The free provision of dips or sprays is

of doubtful long-term value, except perhaps to nomadic people, since the ultimate widespread practice of tick control must arise from the individual's appreciation of its need and economic value. The need for tick control is most apparent with high-yielding stock, and thus the raising of husbandry standards by such measures as improved fencing, adequate provision of water, pasture and livestock improvement, and external and internal parasite control, all make their contribution. Improved livestock will call for tick control measures and the increased productivity will compensate for the expenses involved.

The distinction between tick control (reduction of tick numbers) and tick eradication must be appreciated. Tick control is needed in order to reduce the mechanical damage caused by ticks, but it is sometimes desirable to retain some ticks in order to perpetuate an immunity to tick-borne disease. Tick control is practiced in ranching areas where attention to individual animals is impossible, and it is also desirable but not essential as a preliminary stage in enzootic disease areas before eradication is attempted.

Control is achieved by dipping either at longer intervals than are needed to kill all ticks, thus allowing some adult ticks to engorge and reproduce, or by dipping only during the season when ticks are numerous.

Eradication of ticks or tick-borne disease

The area of eradication must be defined. A large-scale scheme is most likely to be effective when the area is bounded by natural barriers or by the ecological limits of the ticks. It is least likely to be effective when bounded by similar areas where tick control is not practiced. It can be effective on single farms or small areas which are surrounded by ticks, providing fencing is good, stock movement is prohibited, and dipping is meticulous.

The species of ticks and their bionomics must be more precisely known than for mitigation, especially such factors as their life cycle and survival times under local conditions. The presence of wild animal hosts, especially of the adult stages of the ticks, may render eradication impossible. The possibility of the reintroduction of ticks by migrating birds or mammals must be envisaged.

Livestock owners must accept and comply with supervision and compulsory enforcement of dipping procedures and stock movement. This normally implies that some degree of tick control must already be

in operation, and its benefits recognized, so that the majority of owners will support and assist in the enforcement of the more irksome aspects of the regulatory measures.

With the exception of recently introduced and localized foci of ticks or disease, eradication schemes should be an extension and consolidation of existing tick control by livestock owners. This presupposes the existence of dips and sprays and familiarity with their use, but state assistance may be needed both to ensure dipping facilities over the entire area and possibly to subsidize the cost of ixodicides.

Domestic stock of all species and ages may also need to be treated. This would probably include domestic stock which are not normally treated effectively. For this purpose, adequate facilities would have to be provided.

The types and strengths of ixodicides which may be used must be specified, and provision made for the sampling and testing of washes. The dipping interval must be that which is most efficient, even though its frequency causes inconvenience to stockowners. For eradication, the interval may have to be shorter than that which has proved adequate for reasonable tick control on farms, and modification of the interval may have to be made, or the ixodicides may have to be changed because of resistance during the course of eradication, if it is found that complete tick control is not being achieved.

Stockowners must keep registers of dip strengths, dipping dates and numbers of livestock immersed. The cause of all death and illness must be ascertained and, if necessary, quarantines enforced. Central records of tick and disease incidence will indicate the progress of the campaign and the need to investigate any failure to control.

Having decided on the procedure and the adequacy of the physical plant, efficient and sympathetic staff must be available for consultation, assistance, and if necessary, enforcement of control measures. They must be able to ensure that tick and disease control is being achieved on all stock.

Prevention of the introduction of ticks or tick-borne disease

The danger of such introduction applies to all countries and areas which are at present free of tick-borne disease or which have been freed by eradication. The latter are more vulnerable, since ticks could certainly re-establish themselves, but in other countries the environment may not be suited to permanent colonization.

The most likely source of introduction of ticks is the live animal, domestic or wild. Fodder, bedding and packing are less likely sources, except over short distances. Migratory animals, and especially birds, also transport ticks.

Imported animals from suspect areas should be quarantined under tick-free conditions before departure and treated at least twice with an ixodicide at the highest safe dose. On arrival, they should again be quarantined, if possible under tick-proof conditions, and the stable refuse destroyed. While in quarantine, the animals should again be treated with ixodicide at least twice, and carefully examined before release. The tick strains mostly likely to be introduced are the strains which are resistant to ixodicides, therefore the ixodicide used should be one against which no resistance has been observed, and it should be applied at the highest safe concentration. Tick species likely to escape surface application of ixodicides are the larvae and nymphae of *Rhipicephalus evertsi* and *Otobius megnini*, which are deep in the ears, and special attention should be paid to treatment of this site. Fodder from cultivated crops and processed food are likely to be safe, but hay and crops which have been grazed are dangerous, and importation should be forbidden or fumigation treatment applied.

Migratory birds may carry and spread ticks of livestock, but since these migrations have been in operation for centuries, any areas suitable for the permanent survival of a species have already been colonized by these ticks. Sporadic outbreaks of foreign tick-borne disease may result from the introduction of these migrant ticks in areas unsuited to the permanent establishment of the tick. Such outbreaks would be dealt with on occurence by the quarantine of the affected herds.

The greatest importation danger is the introduction of a tick-borne disease, especially one which is capable of being spread by mechanical means, or is capable of infecting the indigenous ticks, since detection of the premune carrier is so difficult. The inoculation of large quantities of blood into spenectomized animals, or the feeding of suitable tick vectors on the imported animal, and the subsequent feeding of the molted or hatched stages on susceptible stock, are the only reliable methods, but even these methods would not succeed on every occasion.

Choice between dipping and spraying

For the owners of small numbers of the larger animals such as cattle, hand sprays are the only possible means of application of dips, and for small animals, either hand sprays or small simple tanks are suitable.

Communal schemes, or individuals with large numbers of stock, must use either power sprays or dip tanks. When properly used, each is fully effective. The advantages and disadvantages are discussed in Chapter III. Factors of depletion must be carefully watched. This is particularly true of sprays, where undue confidence in freshly made-up spray wash of the correct strength is likely to obscure the recognition of the serious depletion which may take place after 100 or 200 animals have been passed through.

Choice of ixodicides

It is almost impossible to summarize this subject, as every country has its own particular needs and circumstances.

For the eradication of ticks and control of disease, toxaphene is the chemical of choice because of its residual properties, but its higher cost and its toxicity to calves and dogs must be borne in mind. Arsenic and BHC are still the preferred chemicals for general tick control. Arsenic cannot be used in sprays, but it is the most economical and stable of all the agents used in dip tanks.

The organo-phosphorus compounds are still largely reserved for use against *Boophilus* ticks resistant to the three above-mentioned compounds. In the higher dose range, they are efficient against all species of ticks, but their efficiency against three-host ticks and their toxicity to stock after prolonged short-interval dipping has not yet been adequately established.

DDT is not recommended, except for the control of resistant *Boophilus*. In the United States, restrictions on chemical residues in animal products may preclude the use of some compounds.

Ixodicide	Strength used, given as a percentage weight/volume		
	Short interval	Long interval	Cleansing
	5 to 7 days	2 to 5 weeks	single application
Arsenic	0.16	0.175-0.20	—
Asuntol	0.03	0.06	0.75
BHC (gamma)	0.025-0.035	0.035-0.050	0.05
DDT (para para)	0.25	0.50	—
Delnav	0.05	0.10	0.15
Diazinon	0.05	0.10	0.15
Dieldrin	0.05	0.10	—
Toxaphene	0.25	0.50	0.50

Resistant strains of ticks

Only the *Boophilus* species, *R. sanguineus* and *R. evertsi*, have so far developed resistant strains, but there is no doubt that many, if not all, of the tick species which are subjected to ixodicide pressure will eventually develop resistance. There is little positive action that can be taken to avoid the development of resistance. In countries where ixodicides are widely used by individuals, it would be desirable to prevent the uncontrolled use of all and every compound; this would prevent the complicated patchwork of resistances which exist in many countries. It would be desirable to retain one of the newer compounds in reserve, until such time as resistance to all the others is widespread. Once resistance is established and confirmed, the procedure is to change the dip washes to an unrelated chemical group, or to add an unrelated chemical group to the existing wash.

The timing of application

For the eradication of ticks and the control of tick-borne disease, it is recommended to dip at 5-to-7-day intervals.

For the reduction of tick numbers, it is suggested either to dip regularly at 2-to-3-week intervals, or at 7-to-14-day intervals during peak periods, when there is a marked seasonal incidence of the ticks, and rarely, or not at all, during other seasons.

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